

The Application of Life-Cycle Analysis to Integrated Solid Waste Management Planning for the State of Delaware

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Objective

- Use a planning tool to evaluate multiple alternatives for solid waste management in Delaware
 - Consider cost, emissions, energy consumption
 - Consider scenarios that may differ from current practice

Presentation Outline

- SWM-LCI Background
- Modeling Approach
- Data Collection
- County-specific SWM Strategies
 - Least-cost scenarios
 - Combinations of Curbside Recycling, Yard Waste Composting and Combustion
 - Consideration of Environmental Emissions
- Statewide SWM Strategies
- Alternative SWM Strategies
- Uncertainty analysis
- Summary

Solid Waste Management is Complex: Many Options are Interrelated

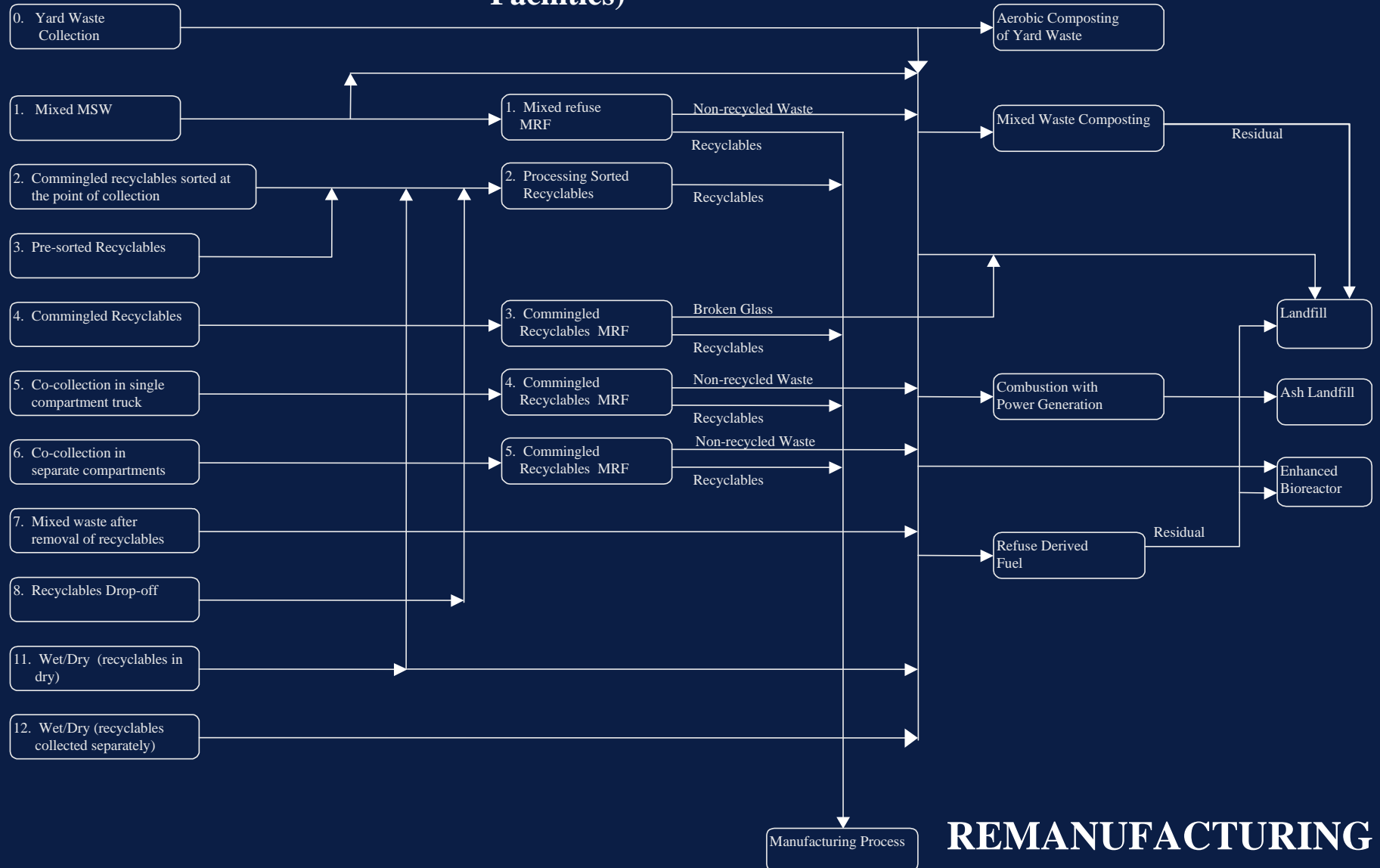
- Recycling vs. waste-to-energy for recyclable paper and plastics (newsprint, cardboard, plastic)
- Relative benefits of landfilling or composting yard waste if we plan to recover methane?
- How do the cost and environmental emissions change if we add a material to a recycling program?

COLLECTION

MRF (Material Recovery Facilities)

TREATMENT composting, combustion

DISPOSAL

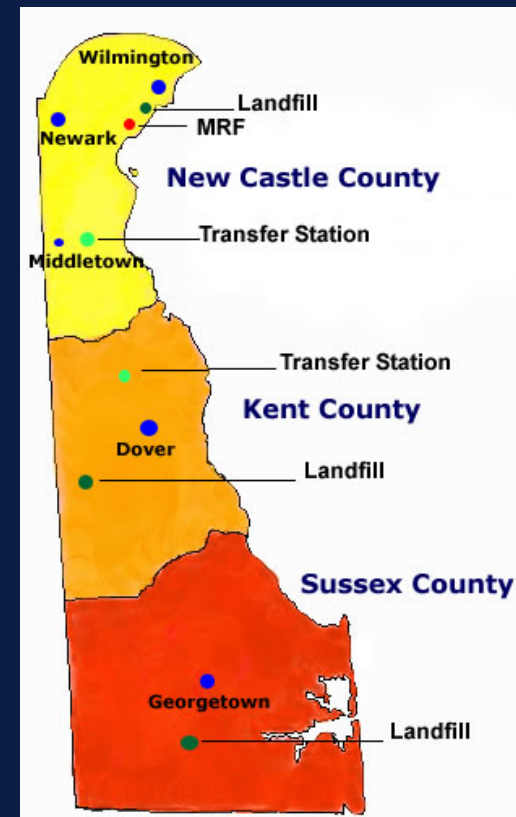


Solid Waste Management Life-Cycle Inventory Model

- A computer model to assist in decision making
 - Quantitative information to screen waste management alternatives
 - cost, energy consumption, emissions
 - Compare many alternatives
 - Identify an optimal solution
 - Model existing waste management system
 - Perform sensitivity analysis on uncertain model inputs
 - The person making a decision will still have to consider “unmodeled” factors

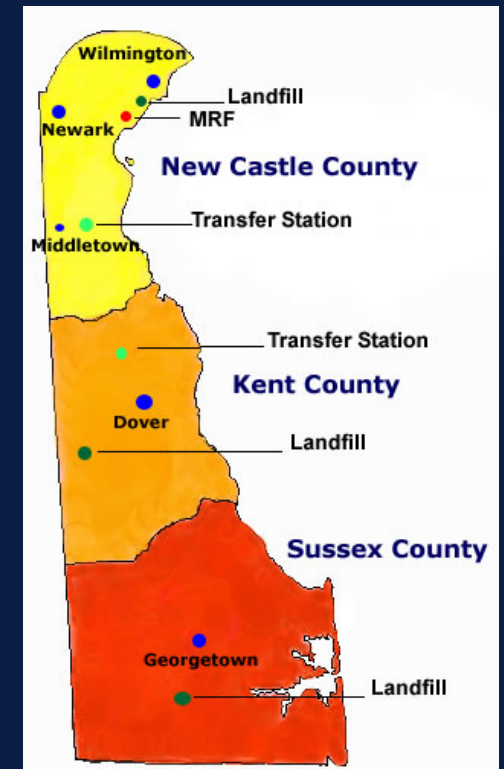
Modeling Solid Waste Management System in Delaware

- New Castle County
 - Urban
 - 64% of the state population
- Kent County
 - Suburban to rural
 - 16% of the state population
- Sussex County
 - Suburban to rural
 - 20% of the state population



Modeling Approach

- Each county was modeled separately
 - Represent individual facilities by county
 - Unique travel distances
 - More realistic
- Challenges
 - Appropriate combination of county-specific strategies to obtain appropriate statewide strategies



Data Collection: Waste Generation and Composition

- Franklin Report for Delaware (2002)
 - Waste generation
- SCS Report (1997)
 - Yard waste
- EPA's Waste Characterization Report: 2000 Update (2002)
- Wastes mapped into 42 categories
- Generation vs. Disposal

Recycling Participation

- Drop Off: Capture rates calculated from amount of material recycled (Franklin)
 - 20% of MSW generated is recovered by Recycle Delaware Program
- Curbside: recovery rate is assumed to be 20% greater than the national average

Waste Collection and Disposal

- Tonnage data provided by DSWA
- Private MSW haulers contacted for route data
 - travel times between stops
 - time from garage to first stop
 - % of volume utilized

Where are we now?

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Base Scenario Development

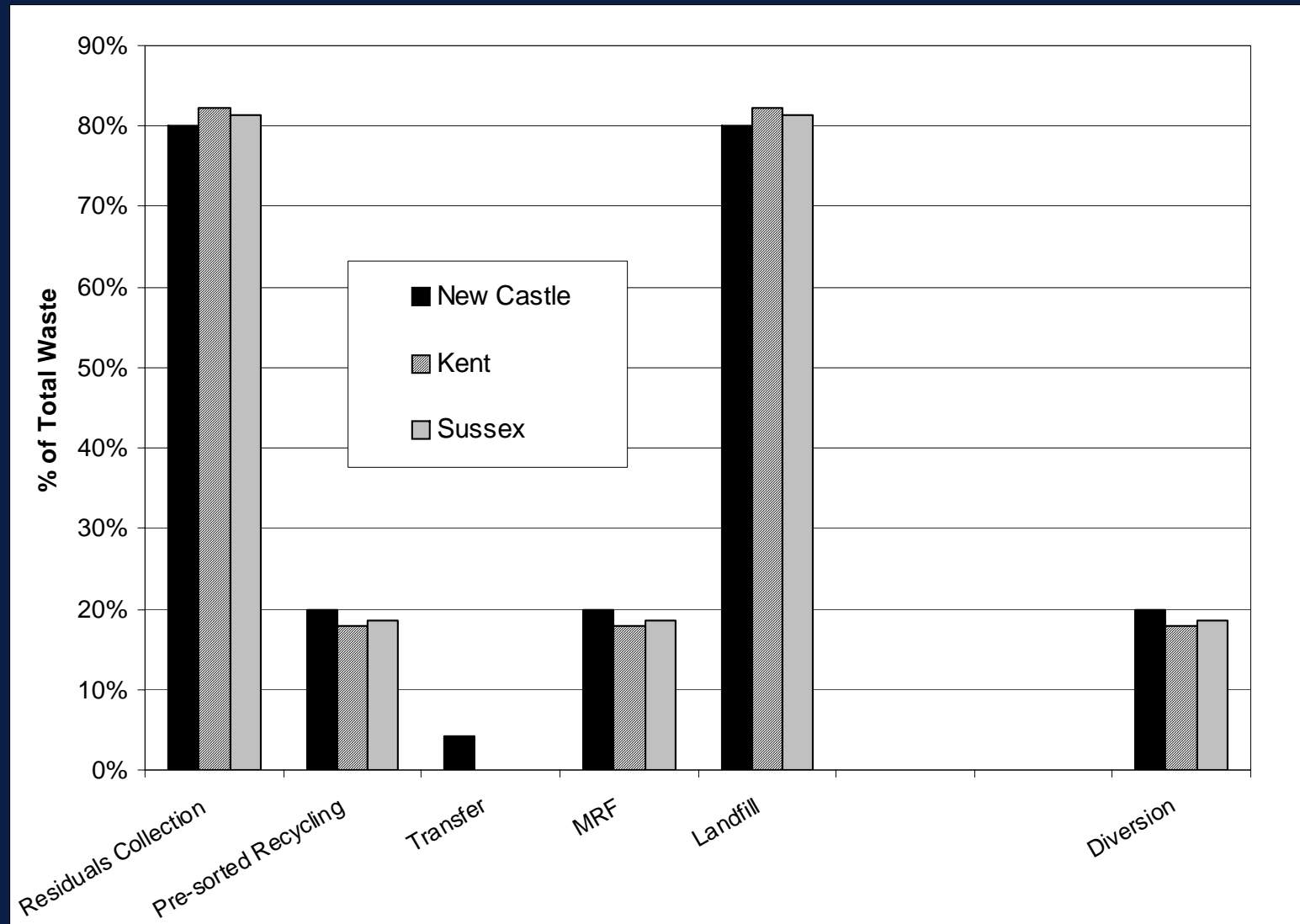
- Current practice in Delaware is represented in SWM-LCI model
- The resultant strategy will serve as a base case (20% diversion) to analyze and compare differences in alternative SWM strategies
- The mass flows through facilities are appropriately represented
 - New Castle County is divided into 2 residential sectors
 - one served by the transfer station
 - one with direct haul to landfill

SWM Strategies

	Least-Cost				Least-GHE	
	Current	I	II	III	IV	V
Pre-sorted MRF	✓	✓	✓	✓	✓	✓
Commingled MRF		✓	✓	✓	✓	✓
Mixed Waste MRF		✓	✓	✓	✓	✓
Yard Waste Composting			✓	✓	✓	✓
Combustion				✓		✓
Landfill	✓	✓	✓	✓	✓	✓

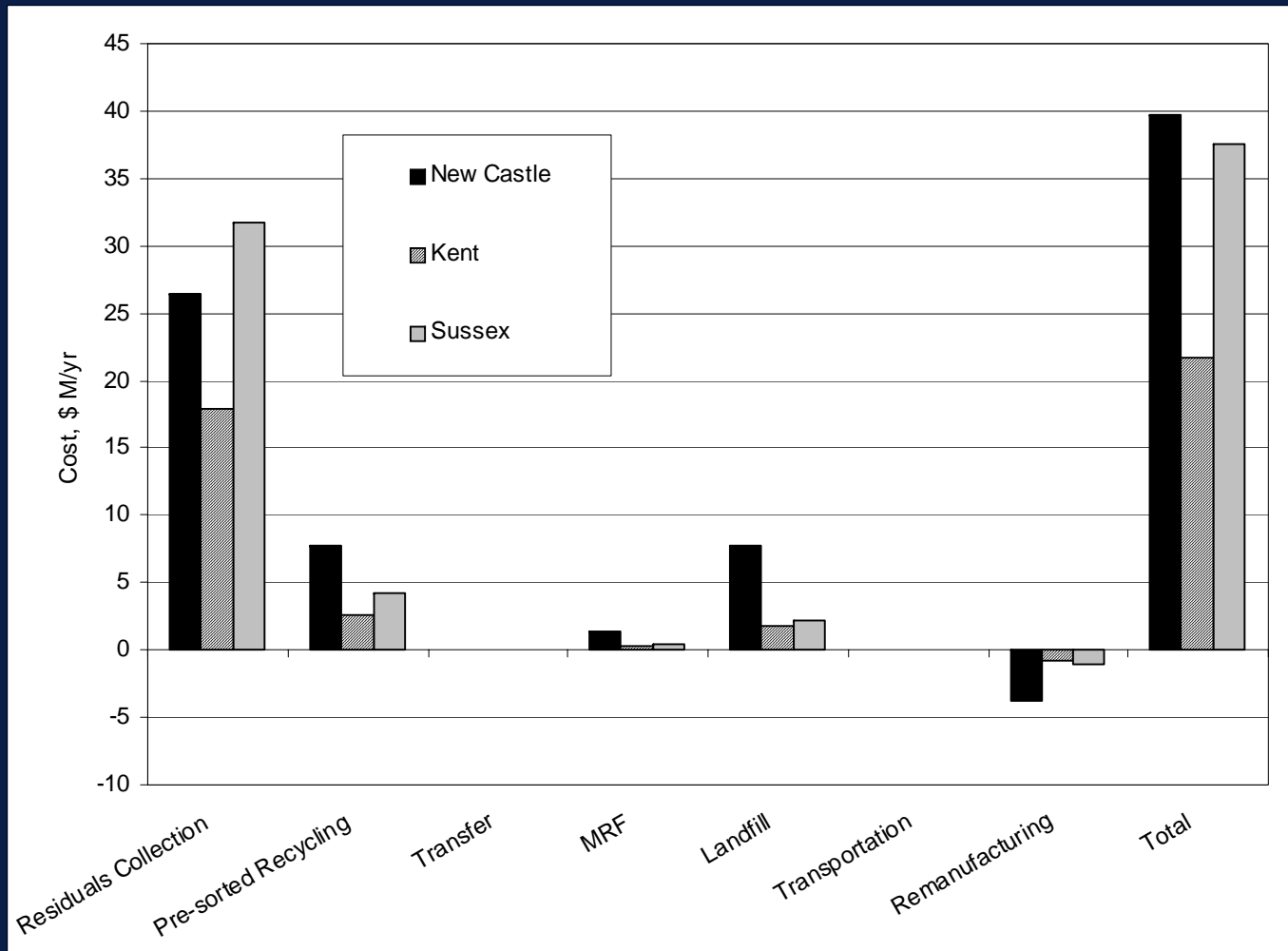
Waste Flow Breakdown by Unit Operations

[current practice (base case)]



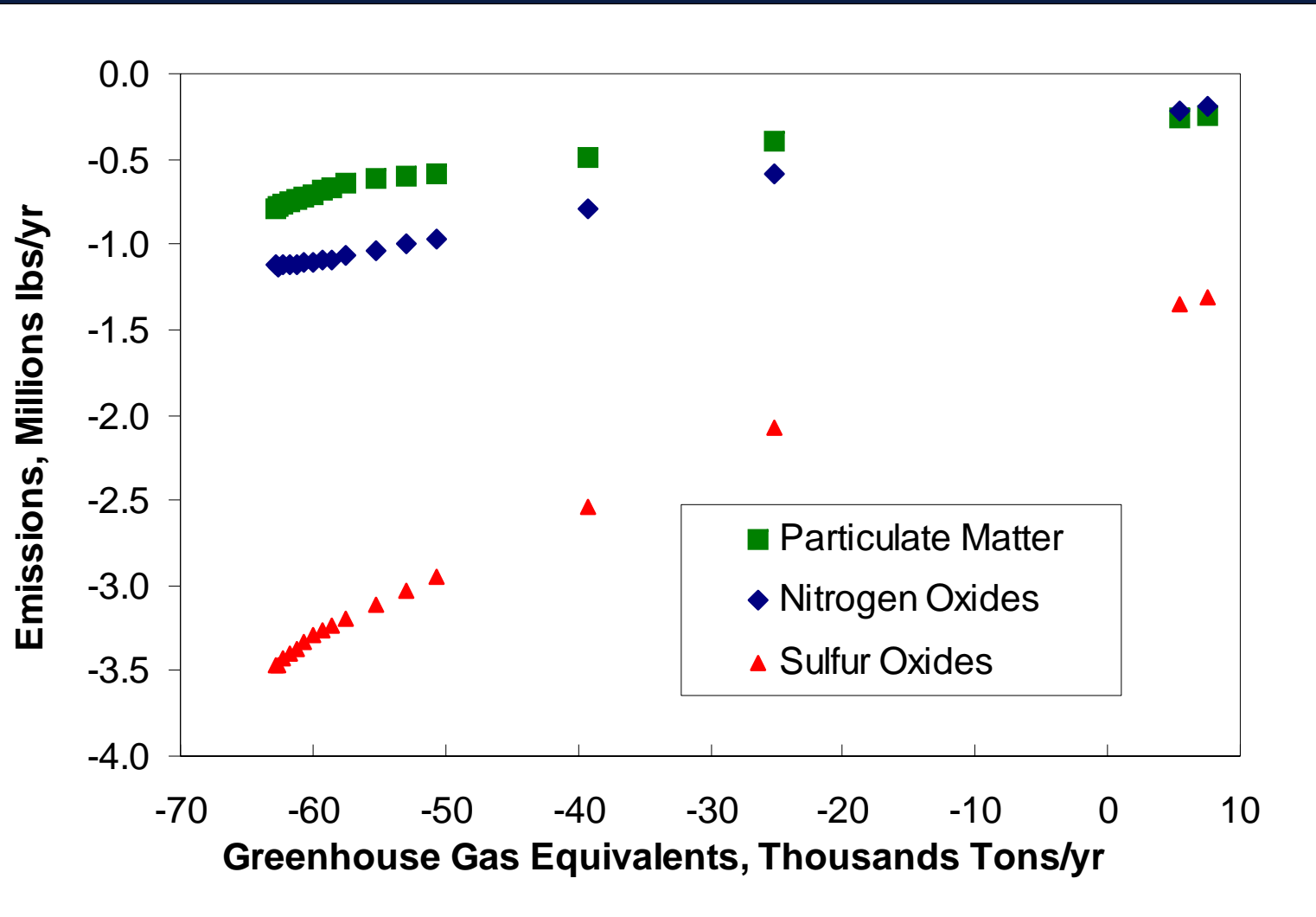
Cost Breakdown by Unit Operations

[current practice (base case)]



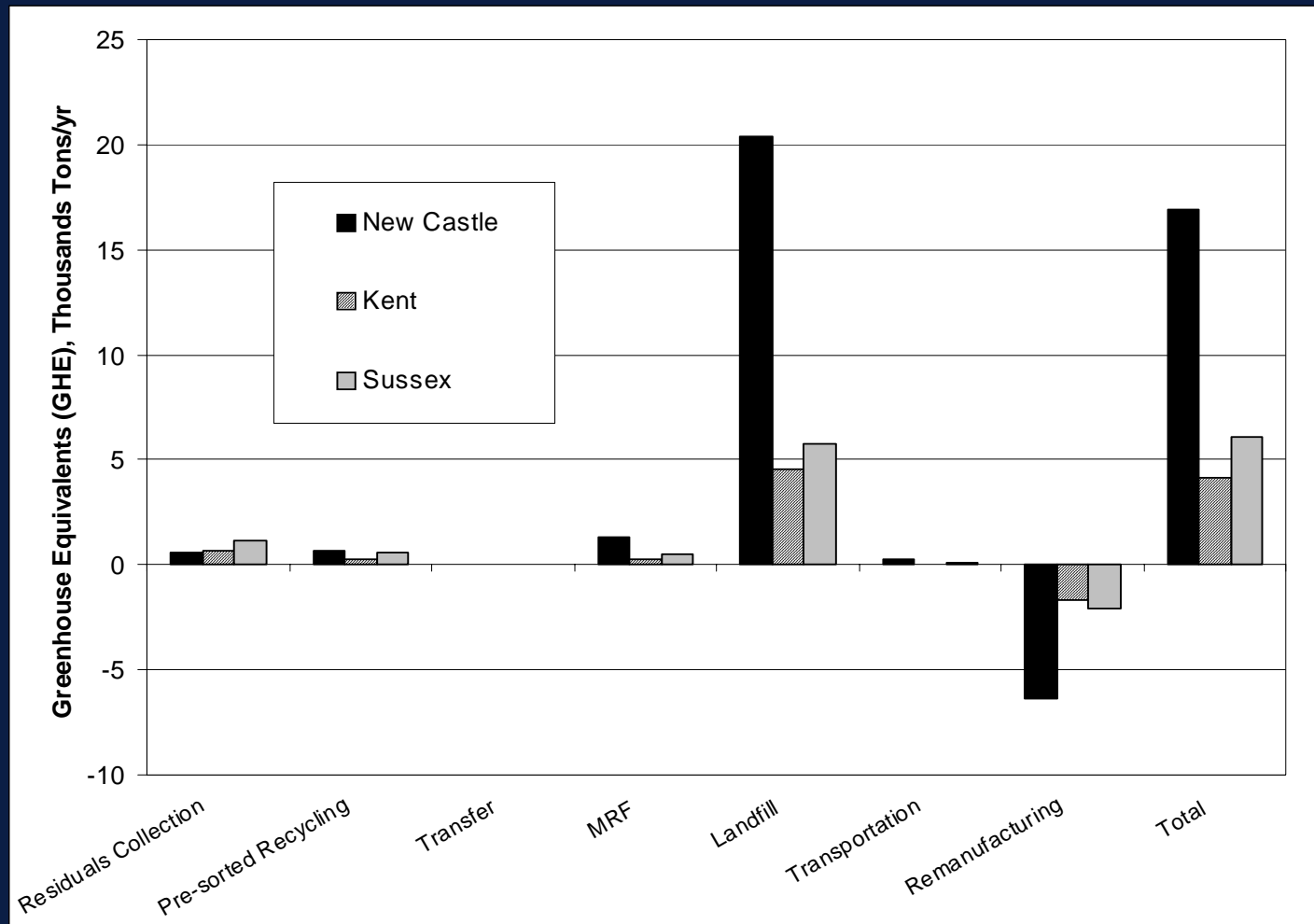
- Costs per ton are higher in rural counties

Indicator Parameters for Environmental Emissions



GHE Breakdown by Unit Operations

[current practice (base case)]



- Recycling results in avoided emissions

Where are we now?

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- County-specific SWM Strategies



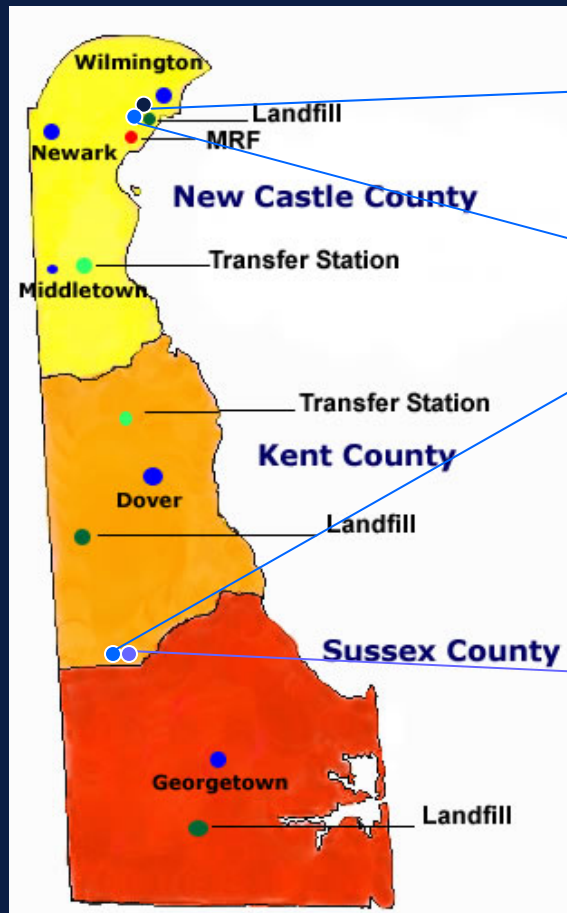
Least-Cost SWM Strategies with

- Curbside Recycling
- Yard waste composting
- Combustion

Recycling, Yard Waste
on
mental Emissions

- Statewide SWM Strategies
- Alternative SWM Strategies
- Uncertainty analysis

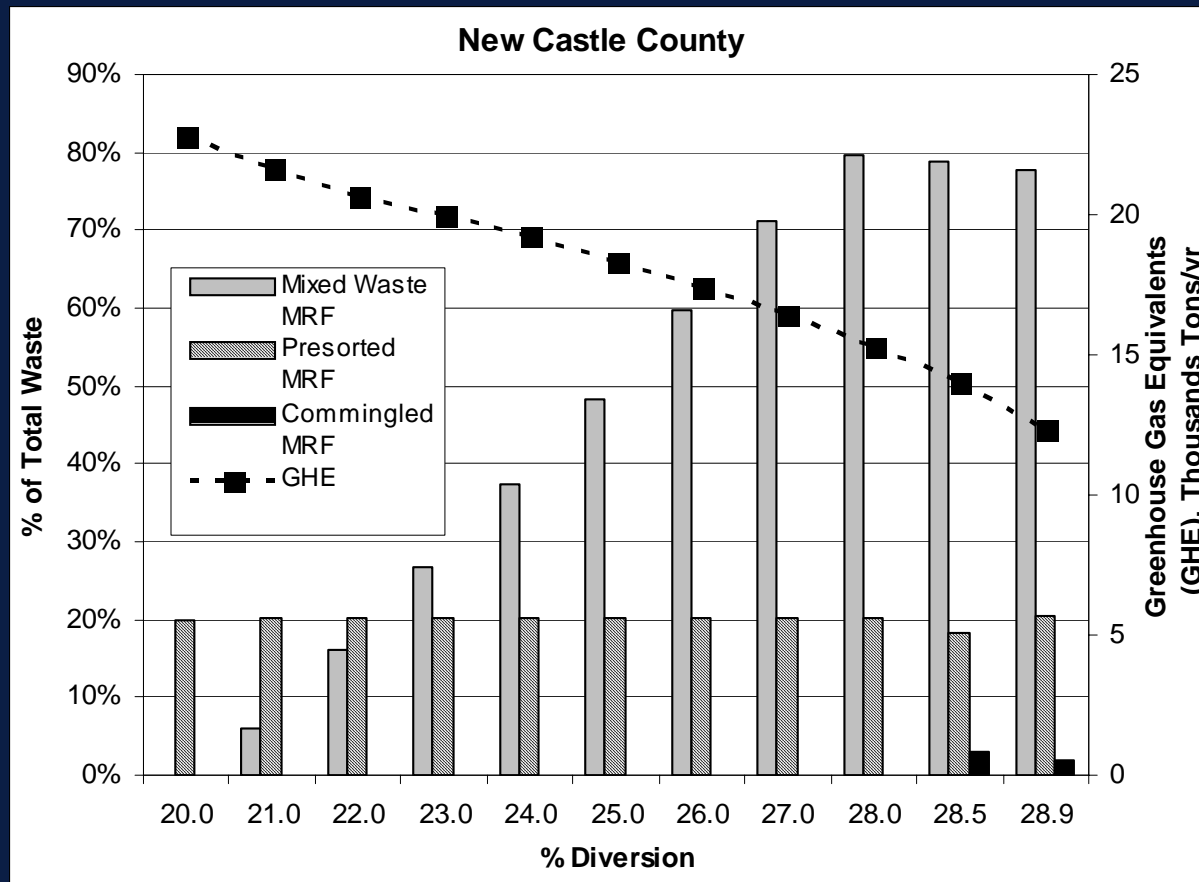
Future Facility Locations



- A combustion facility is assumed to be located near the landfill in New Castle County
- Yard waste composting facilities are assumed to be located on the border of the Kent and Sussex Counties and near the landfill in New Castle County
- A MRF is assumed to be located on the border of the Kent and Sussex Counties

Variation of Mass Flows and GHE with Diversion

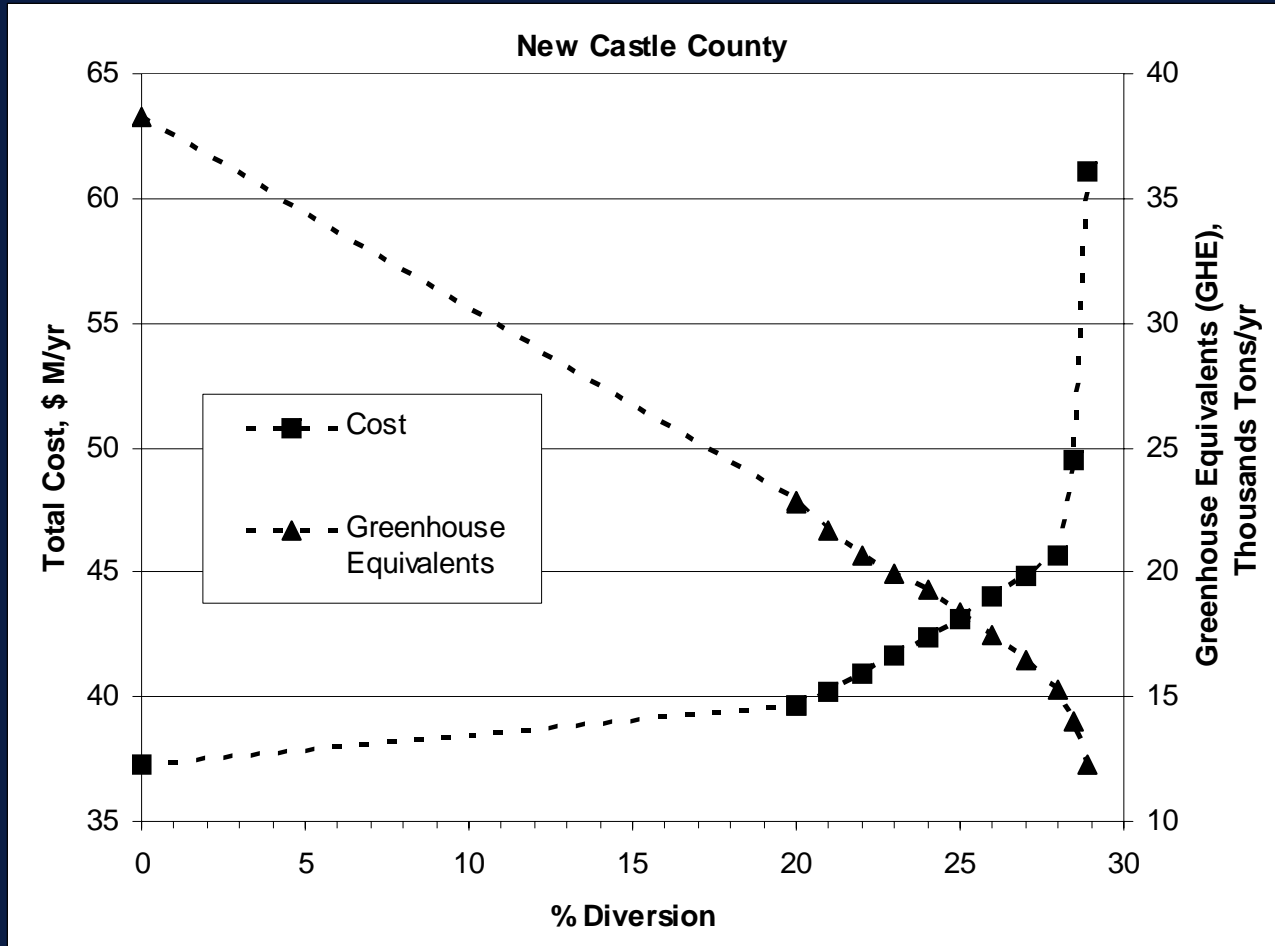
[curbside recycling in New Castle County]



- Commingled recyclables only collected in residential sector 2 in max case
- Up to 28% diversion, pre-sorted and mixed waste MRFs are utilized, curbside recycling thereafter
- Minimum GHE at max diversion

Variation of Cost and GHE with Diversion

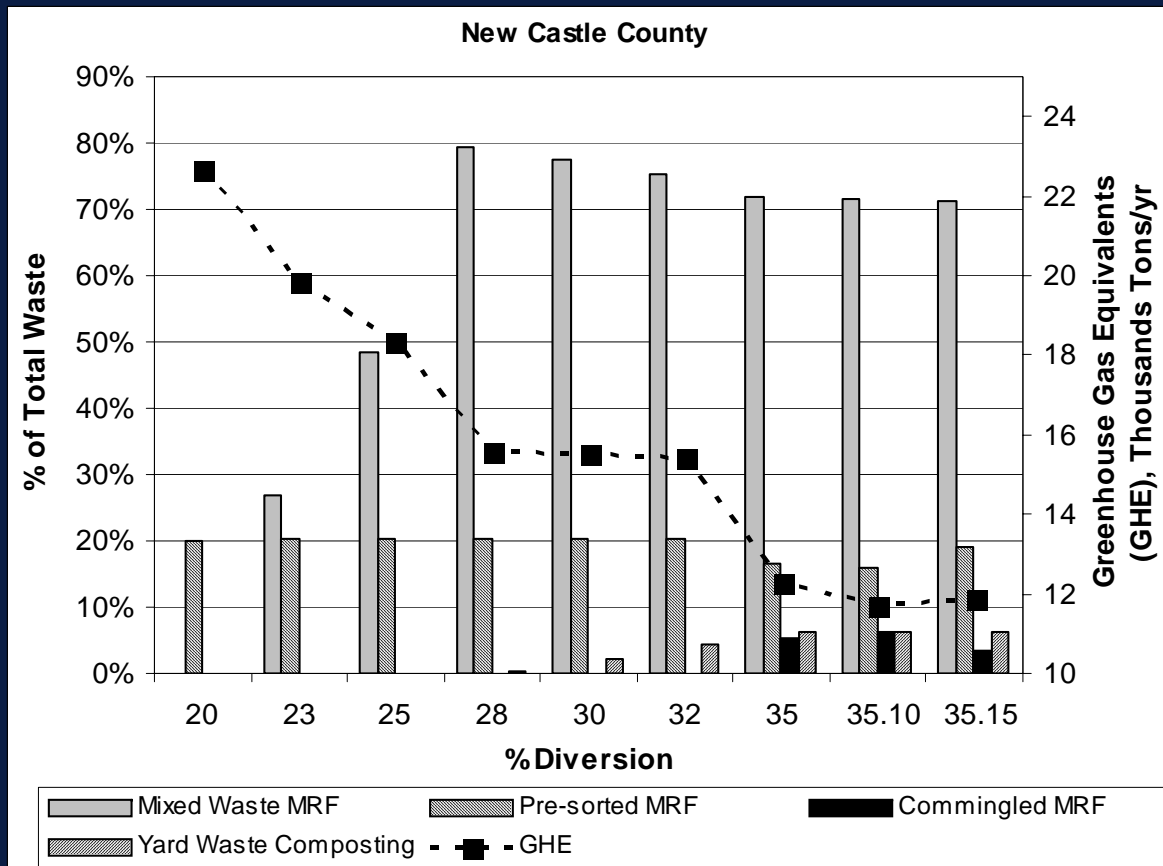
[curbside recycling in New Castle County]



- Cost escalates with implementation of curbside recycling at 28% diversion

Variation of Mass Flows & GHE with Diversion

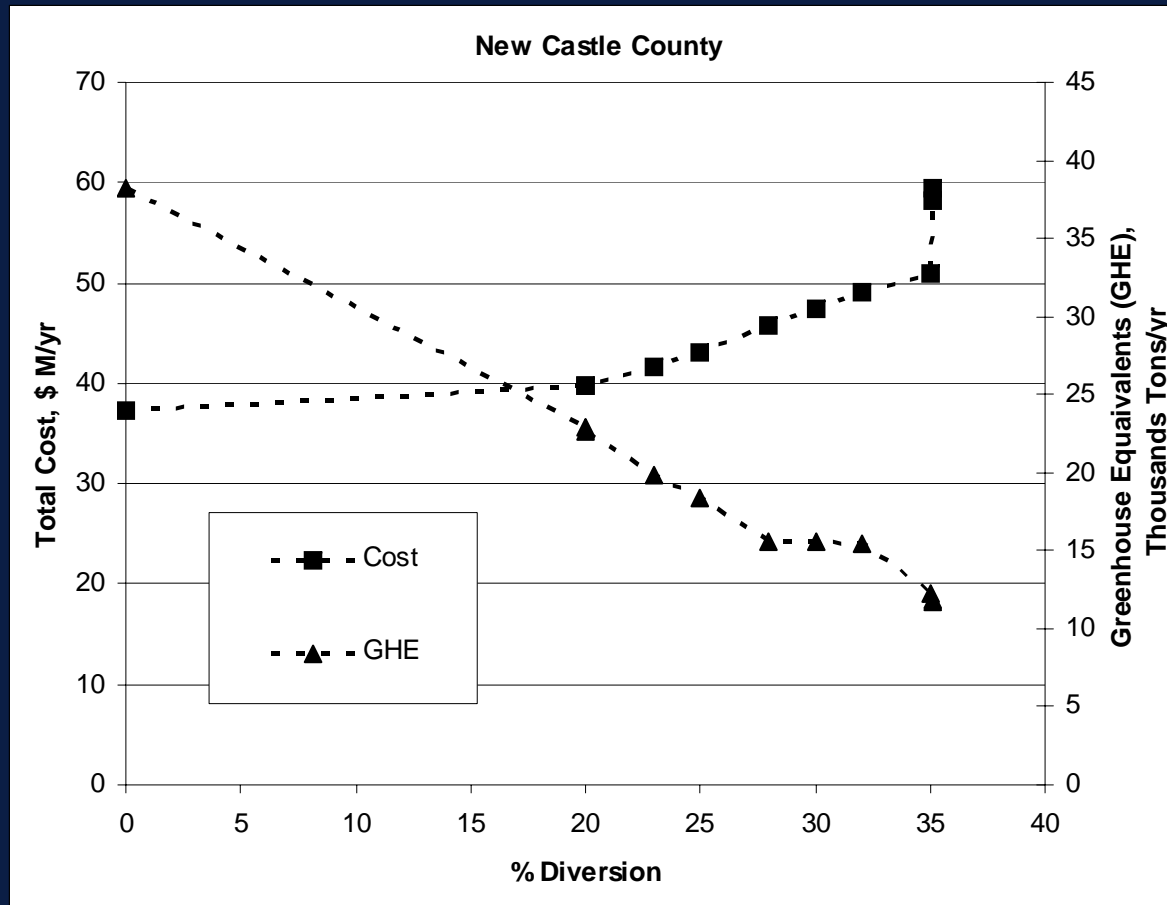
[curbside recycling + yard waste composting in New Castle County]



- Cost of mixed waste MRF < yard waste composting < curbside collection
- GHE does not decrease with implementation of composting in contrast to recycling

Variation of Cost & GHE with Diversion

[curbside recycling + yard waste composting in New Castle County]

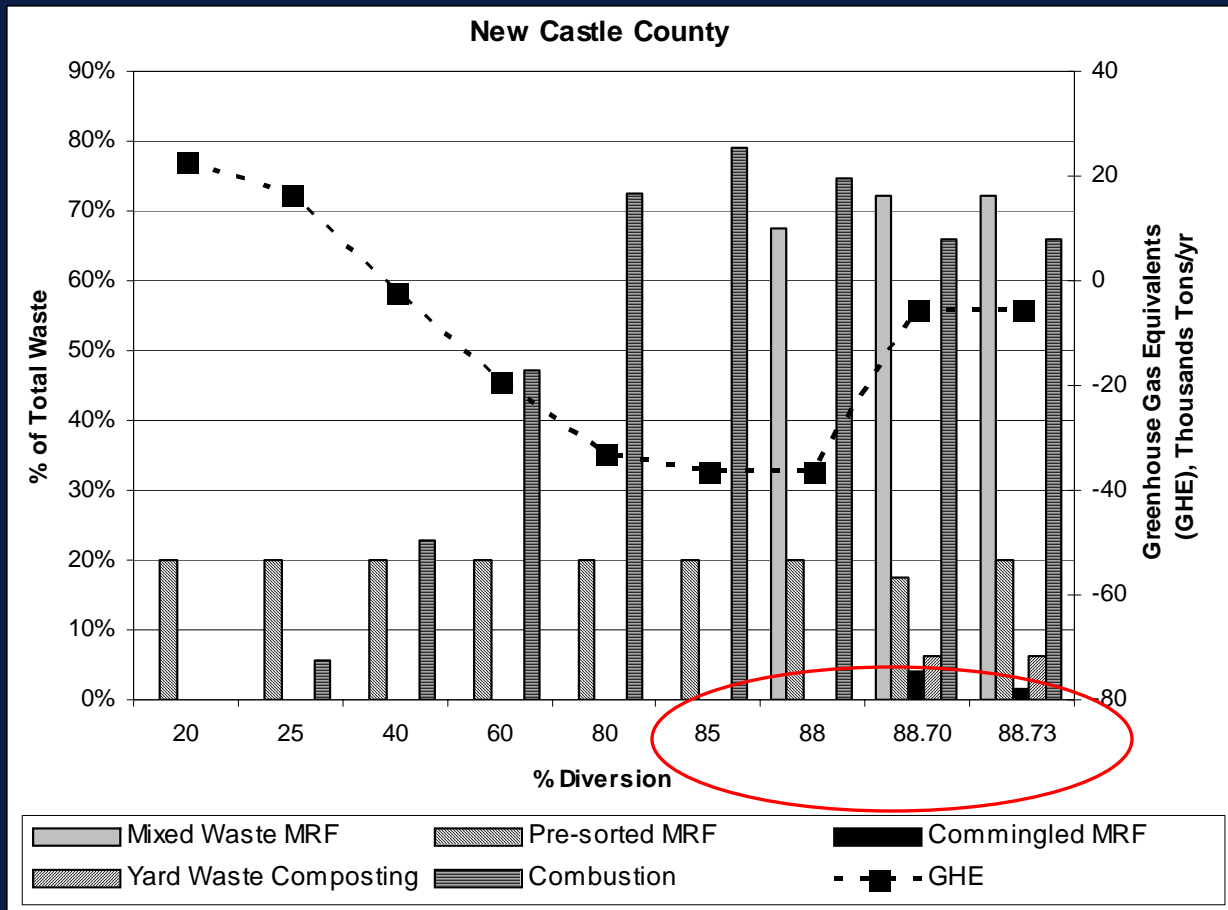


- Steep increase in cost with implementation of curbside recycling

Variation of Mass Flows & GHE with Diversion

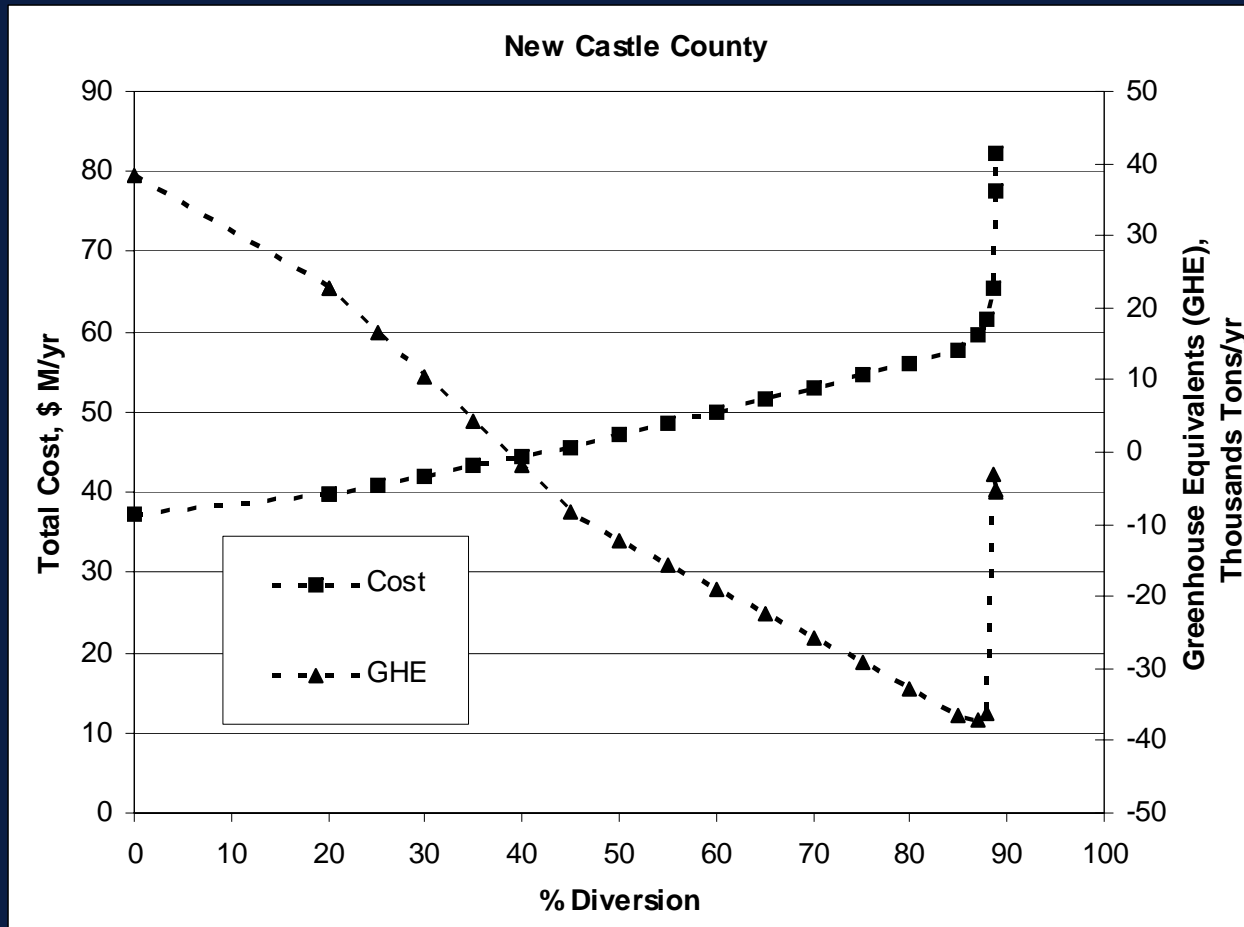
[curbside recycling + yard waste composting + combustion in New Castle County]

- Combustion is utilized to meet diversion constraint because it is estimated to be less expensive than alternatives
- Note partial implementation of combustion & utilization of a mixed waste MRF
- GHE increases near maximum due to composting



Variation of Cost & GHE with Diversion

[curbside recycling + yard waste composting + combustion in New Castle County]



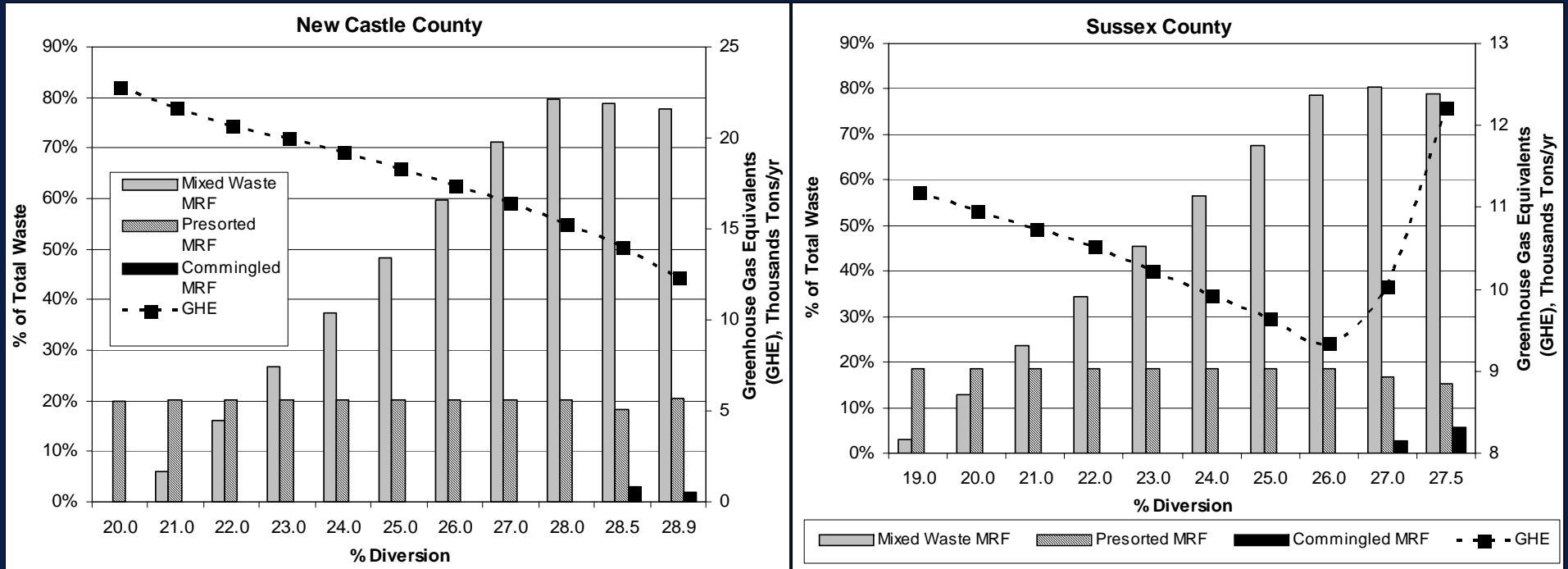
- Cost and GHE increase near maximum case illustrate extremes of numerical solution
- Ash content of yard waste leads to use of composting

Comparison of Cost and Emissions

Parameter	Units	Least-Cost						Least-GHE	
		Current	Recycling	Recycling MAX	Recycling + Composting MAX	Recycling + Composting + Combustion	Recycling + Composting + Combustion MAX	No Combustion	Combustion
Cost	\$/year	9.80E+07	1.01E+08	1.62E+08	2.05E+08	9.89E+07	1.92E+08	1.19E+08	1.45E+08
Energy	MBTU/year	-8.84E+05	-2.02E+06	-2.68E+06	-2.27E+06	-1.72E+06	-2.71E+06	-2.85E+06	-5.24E+06
Total PM	lbs/year	-1.84E+06	-2.25E+06	-2.35E+06	-2.24E+06	-1.68E+06	-2.32E+06	-2.36E+06	-1.05E+06
NOx	lbs/year	-3.80E+04	-3.22E+05	-3.37E+04	4.94E+05	-3.79E+05	6.88E+04	-4.91E+05	-1.24E+06
SOx	lbs/year	-1.85E+06	-2.15E+06	-2.31E+06	-2.01E+06	-2.42E+06	-1.94E+06	-2.35E+06	-4.88E+06
CO	lbs/year	-1.42E+06	-9.05E+04	-1.77E+06	-1.40E+06	9.12E+05	-1.37E+06	-2.21E+06	3.89E+05
CO ₂ -Biomass	lbs/year	1.78E+09	4.98E+08	5.21E+08	4.66E+08	5.79E+08	3.39E+08	5.25E+08	9.68E+08
CO ₂ -Fossil	lbs/year	-8.96E+07	-6.42E+06	-1.12E+07	7.06E+07	-1.20E+08	5.60E+07	-5.71E+07	-5.54E+08
GHE	tons/year	3.81E+05	3.40E+04	3.19E+04	3.06E+04	1.90E+04	7.02E+03	2.53E+04	-8.04E+04
CH ₄	lbs/year	1.37E+08	1.22E+07	1.17E+07	7.32E+06	1.24E+07	-2.16E+05	1.15E+07	-1.69E+06
Diversion	%	19%	25%	28.34%	34.88%	30%	88.47%	31.03%	85.29%

Variation of Waste Flows, Cost, & GHE with Diversion

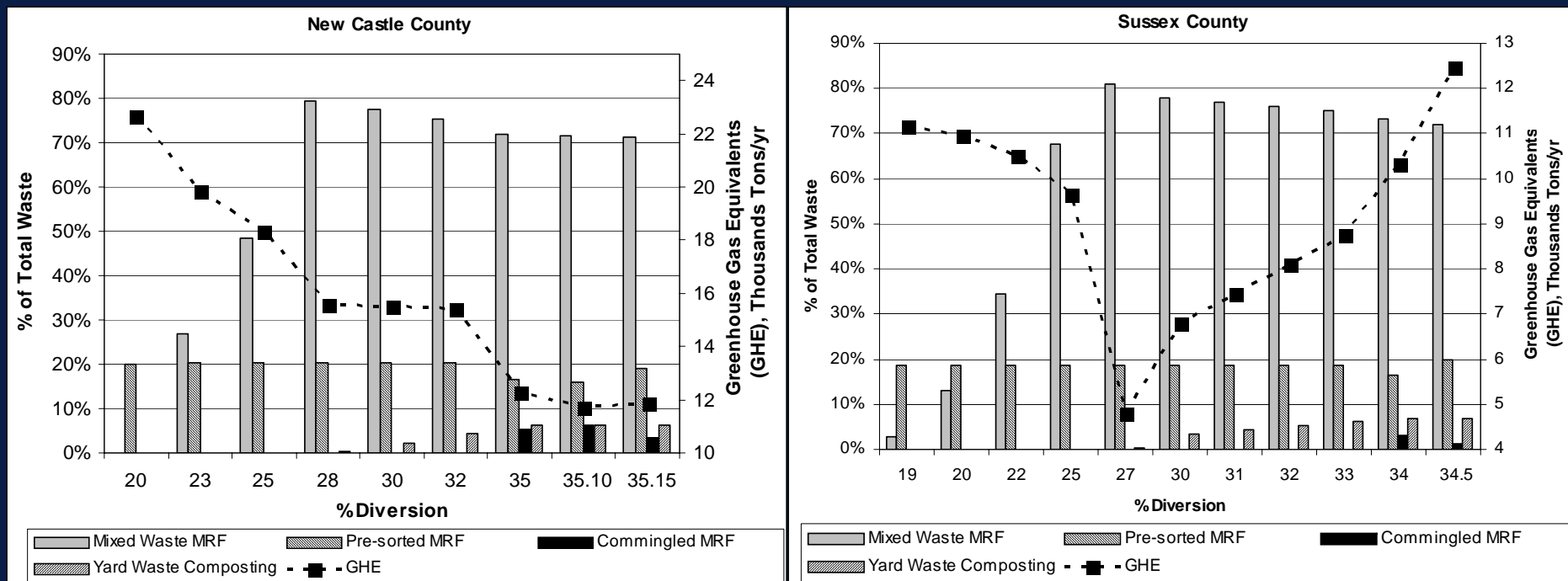
[curbside recycling]



- Similar use of mixed waste MRF which is cheaper
- GHE increases with use of curbside collection in Sussex County
- GHE decrease by 50% in New Castle County, compared to only a 10% decrease in Sussex County

Variation of Waste Flows, Cost, & GHE with Diversion

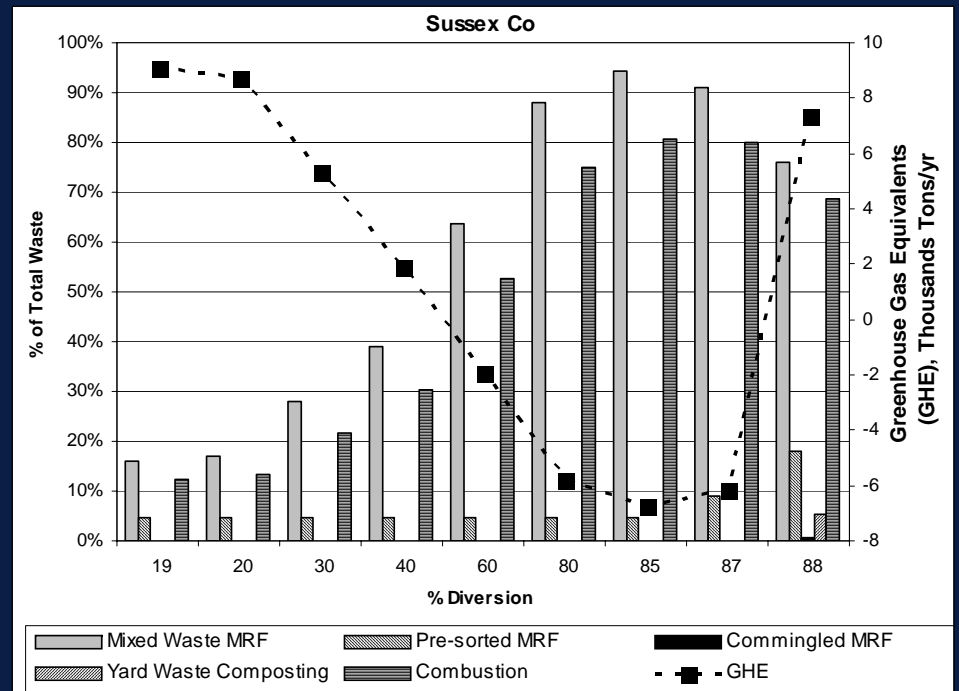
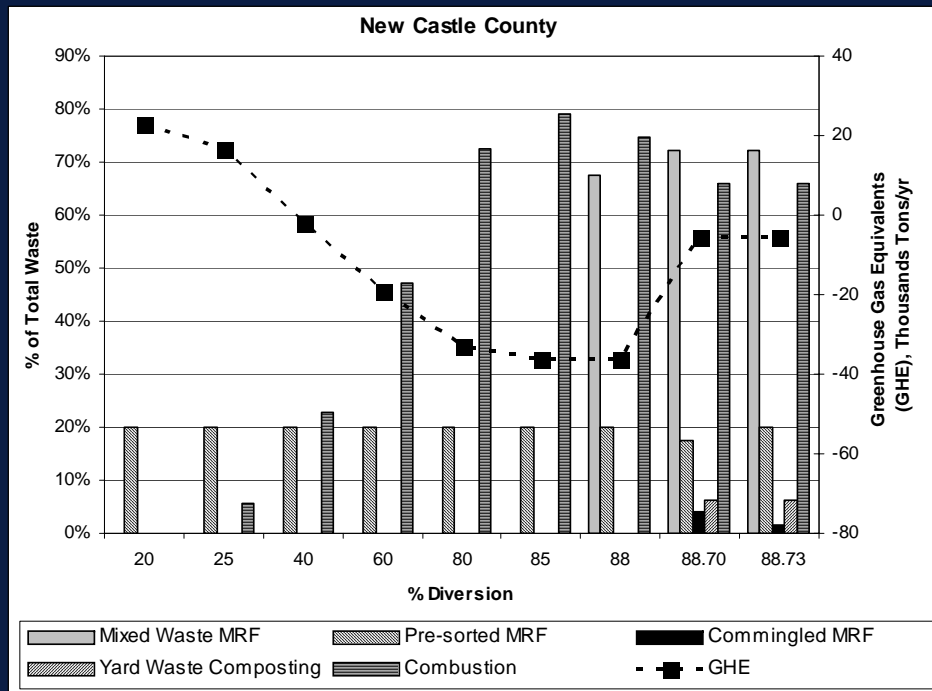
[curbside recycling + yard waste composting]



- Similar use of mixed waste MRF, curbside recycling, yard waste composting
- Utilization of composting stabilizes the emissions in New Castle County scenarios, and increases emissions in Sussex County

Variation of Waste Flows, Cost, & GHE with Diversion

[curbside recycling + yard waste composting + combustion]



- In Sussex County, a mixed waste MRF is utilized upstream of combustion to reduce transport costs
- Composting and curbside recycling only used near maximum diversion with resultant increases in GHE emissions

Where are we now?

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- Least-GHE SWM Strategies with Curbside Recycling + Yard Waste Composting + Combustion
- Statewide SWM Strategies
- Alternative SWM Strategies
- Uncertainty analysis

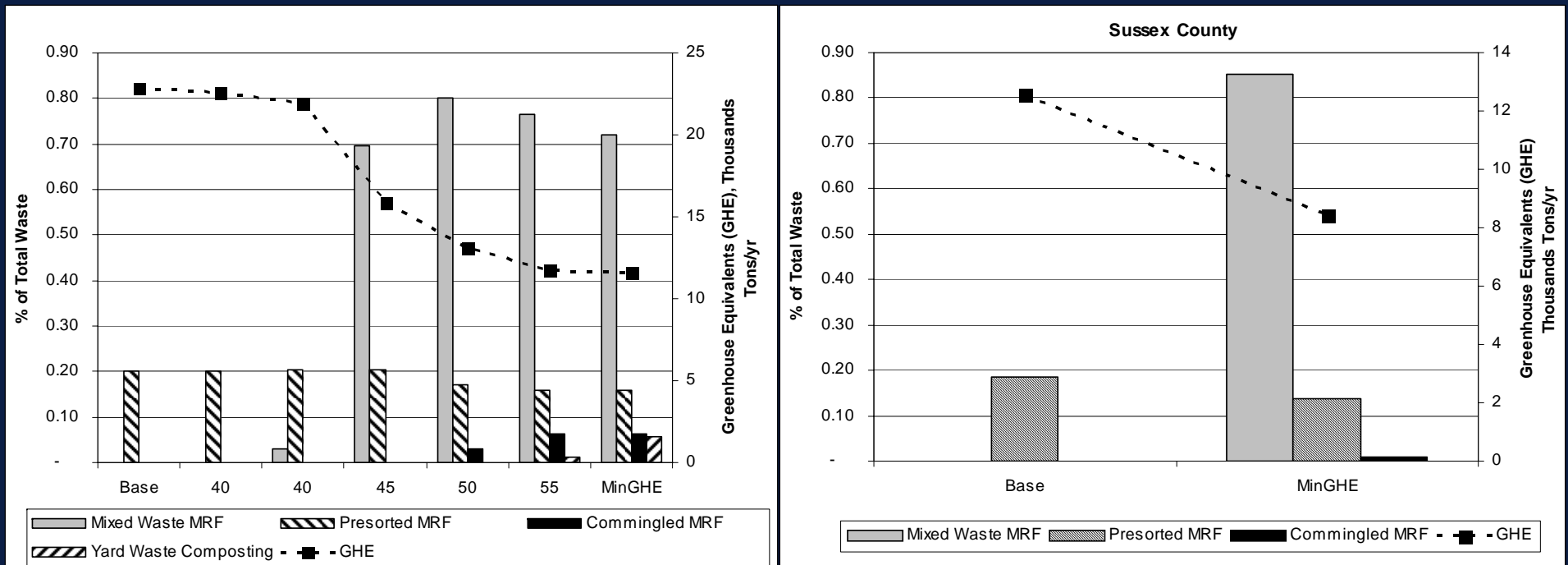


Least-GHE SWM Strategies with
Curbside Recycling + Yard Waste
Composting + Combustion

Environmental Emissions

Variation of Waste Flows & GHE with Cost While Minimizing GHE

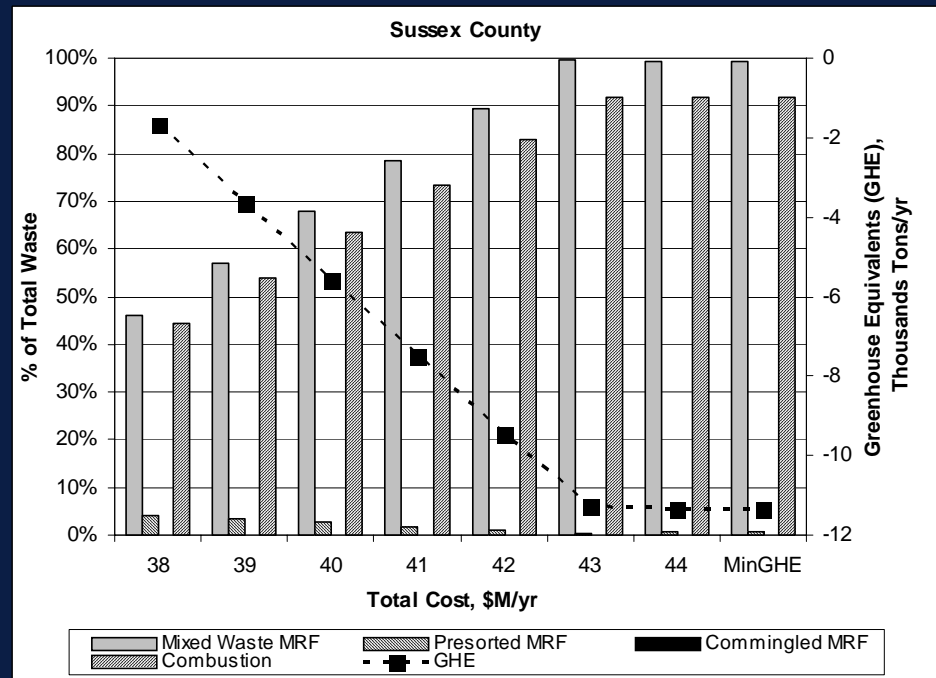
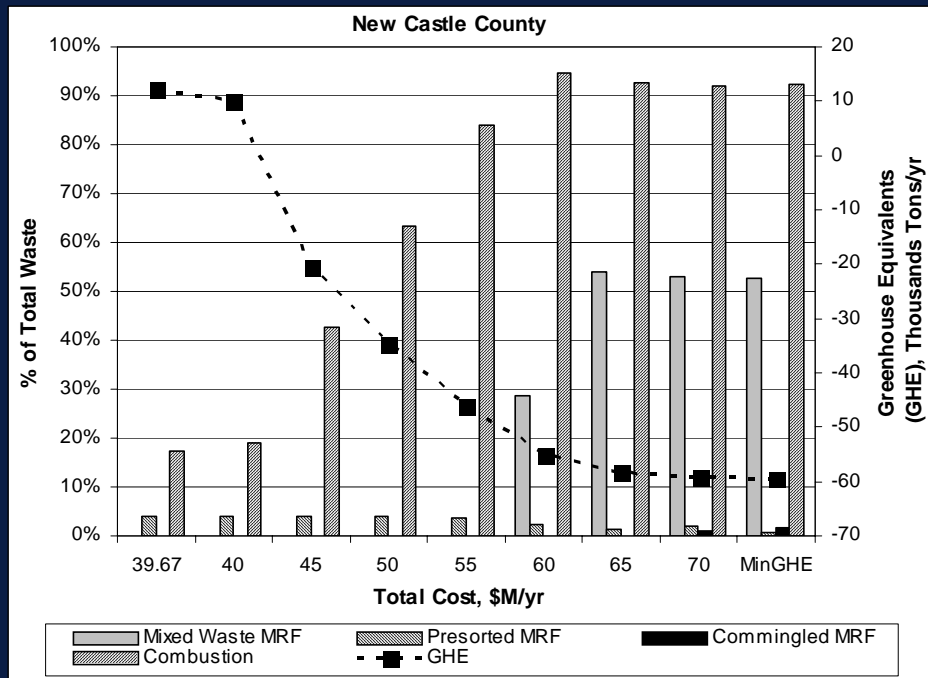
[curbside recycling + yard waste composting]



- Increasing Cost constraint
- New Castle: Drop-off < mixed waste MRF < commingled recycling < composting
- Sussex: only 2 cases due to 5% difference in cost between base case and min GHE

Variation of Waste Flows & GHE with Cost While Minimizing GHE

[curbside recycling + yard waste composting + combustion]



- Increasing Cost constraint
- Combustion most effective but a mixed waste MRF utilized upstream in Sussex County
- GHE levels off prior to min GHE scenario

Comparison of Cost and Emissions

Parameter	Units	Least-Cost						Least-GHE	
		Current	Recycling	Recycling MAX	Recycling + Composting MAX	Recycling + Composting + Combustion	Recycling + Composting + Combustion MAX	No Combustion	Combustion
Cost	\$/year	9.80E+07	1.01E+08	1.62E+08	2.05E+08	9.89E+07	1.92E+08	1.19E+08	1.45E+08
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Total PM	lbs/year	-1.84E+06	-2.25E+06	-2.35E+06	-2.24E+06	-1.68E+06	-2.32E+06	-2.36E+06	-1.05E+06
NOx	lbs/year	-3.80E+04	-3.22E+05	-3.37E+04	4.94E+05	-3.79E+05	6.88E+04	-4.91E+05	-1.24E+06
SOx	lbs/year	-1.85E+06	-2.15E+06	-2.31E+06	-2.01E+06	-2.42E+06	-1.94E+06	-2.35E+06	-4.88E+06
CO	lbs/year	-1.42E+06	-9.05E+04	-1.77E+06	-1.40E+06	9.12E+05	-1.37E+06	-2.21E+06	3.89E+05
CO ₂ -Biomass	lbs/year	1.78E+09	4.98E+08	5.21E+08	4.66E+08	5.79E+08	3.39E+08	5.25E+08	9.68E+08
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Diversion	%	19%	25%	28.34%	34.88%	30%	88.47%	31.03%	85.29%

Observations from County-Wide Summary

- The least-cost and least GHE solutions vary by county
 - Use of a mixed waste MRF upstream of combustion
 - GHE from curbside recyclables collection in Sussex County
- Non-uniform utilization of curbside collection, combustion subject to a cost constraint
- Model led to counter-intuitive results
 - MRF upstream of combustion
 - Effectiveness of yard waste composting influenced by transport distance
- Model can be rerun with alternate assumptions

Where are we now?

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Procedure to Identify Statewide SWM Strategies

- SWM strategies are generated for each county
- Combinations of these strategies are explored to identify
 - Cost-effective diversion strategies
 - GHE-minimizing strategies at different costs

Identify the Cost-effective 30% Statewide Diversion Strategy?

DIVERSION				Cost [\$ /yr]			
New Castle	Kent	Sussex	State-wide	New Castle	Kent	Sussex	Total
30%	30%	30%	30.0%	42,050,377	21,025,194	35,924,785	99,024,811
30%	35%	30%	30.7%	42,050,377	21,312,793	35,924,785	99,317,194
30%	30%	35%	30.9%	42,050,377	21,025,194	36,812,223	99,403,794
30%	40%	25%	30.5%	42,050,377	21,612,793	35,924,785	99,258,166
35%	25%	20%	30.7%	43,245,513	20,778,283	35,145,802	99,169,597
35%	20%	25%	30.9%	43,245,513	20,485,900	35,524,785	99,256,197
35%	25%	20%	30.7%	43,245,513	20,778,283	35,145,802	99,169,597
35%	20%	20%	30.0%	43,245,513	20,485,900	35,145,802	98,877,214
40%	20%	20%	33.3%	44,440,648	20,485,900	35,145,802	100,072,350
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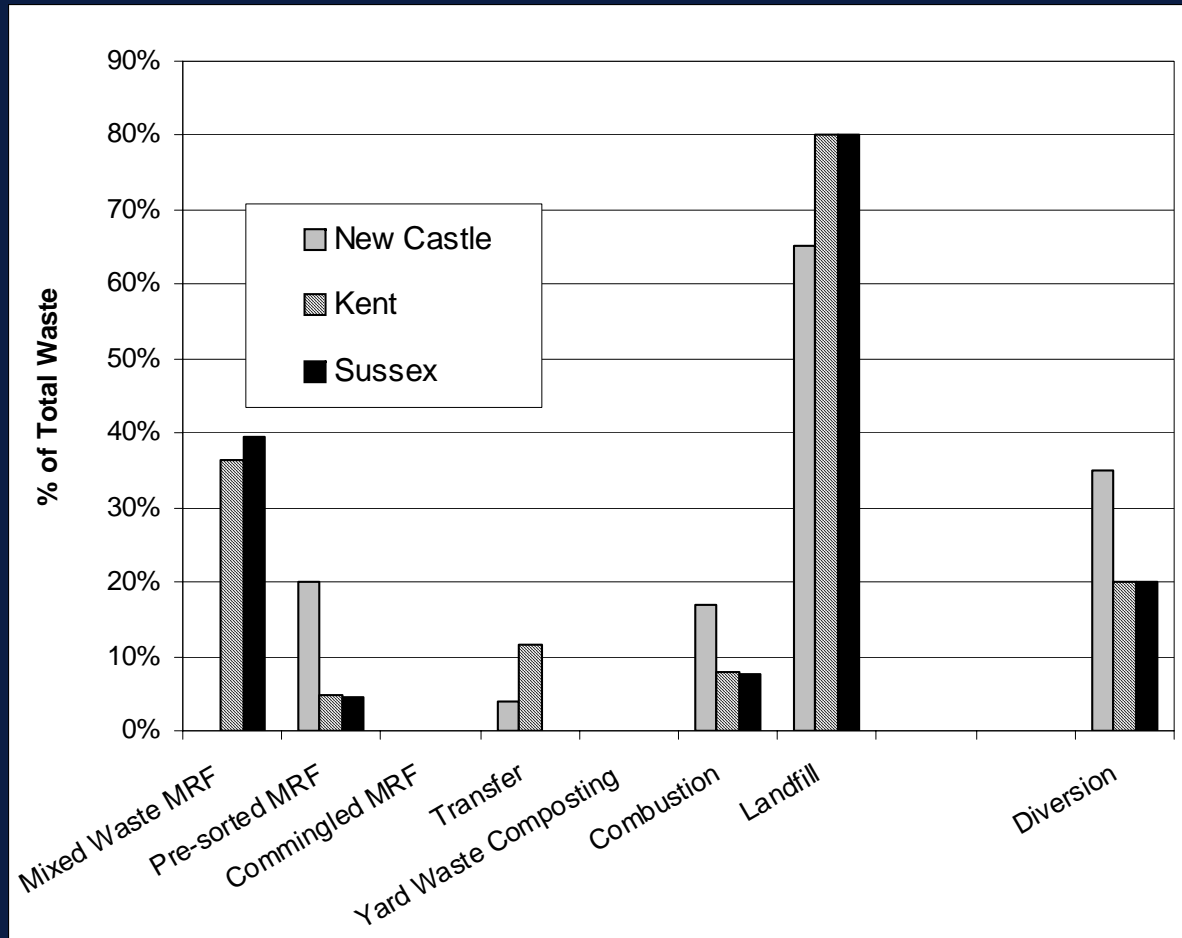
Uniform diversion is not least cost case

Least-Cost 30% Statewide Diversion

For each county approximately 17 SWM strategies exist (20 – 88% diversion):
 $17 \times 17 \times 17 = 4,913$ combinations should be analyzed for minimum cost...

Waste Flows in Cost-effective 30% Statewide Diversion Strategy

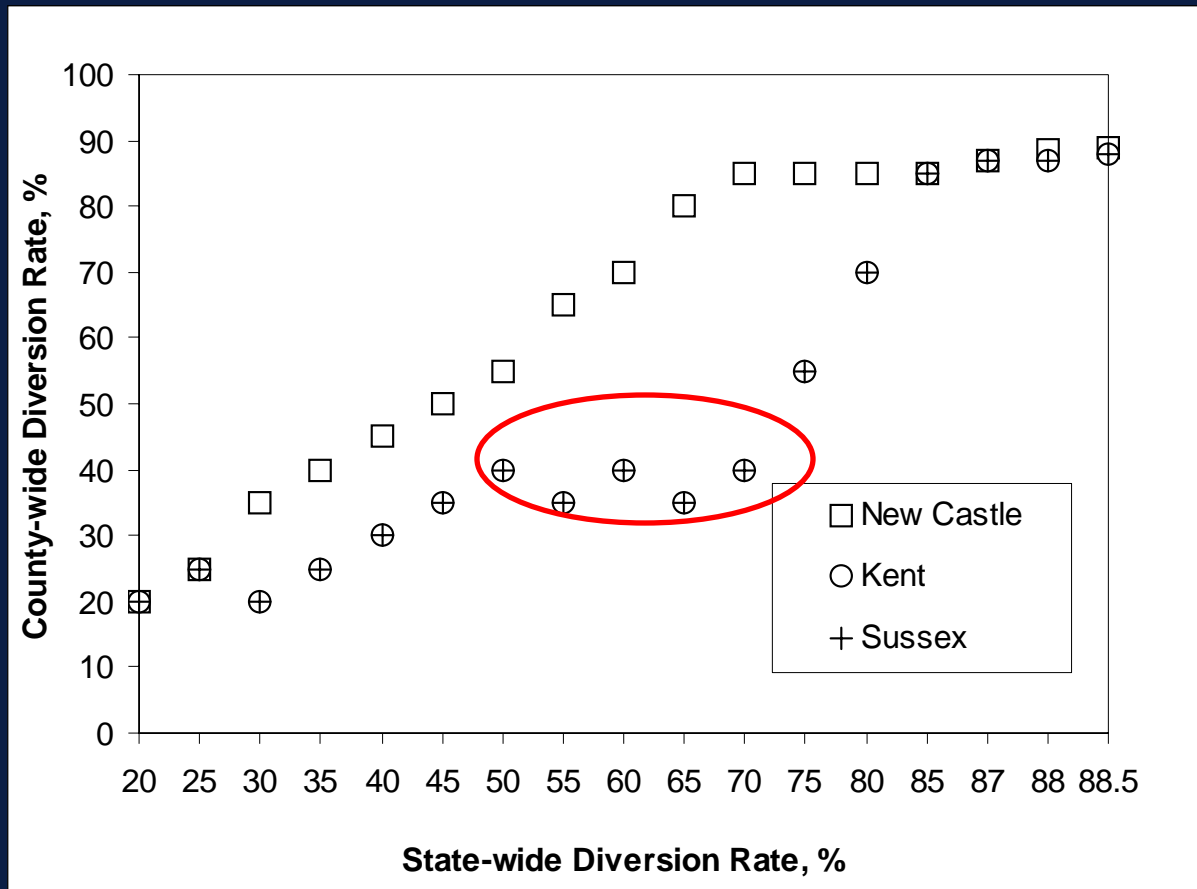
[curbside recycling + yard waste composting + combustion]



- Minimize cost subject to a diversion constraint
- Analysis similar to county specific analyses
- Combustion used subject to cost constraint
- Mixed waste MRF used in rural counties

County-Specific Contribution to Statewide Diversion

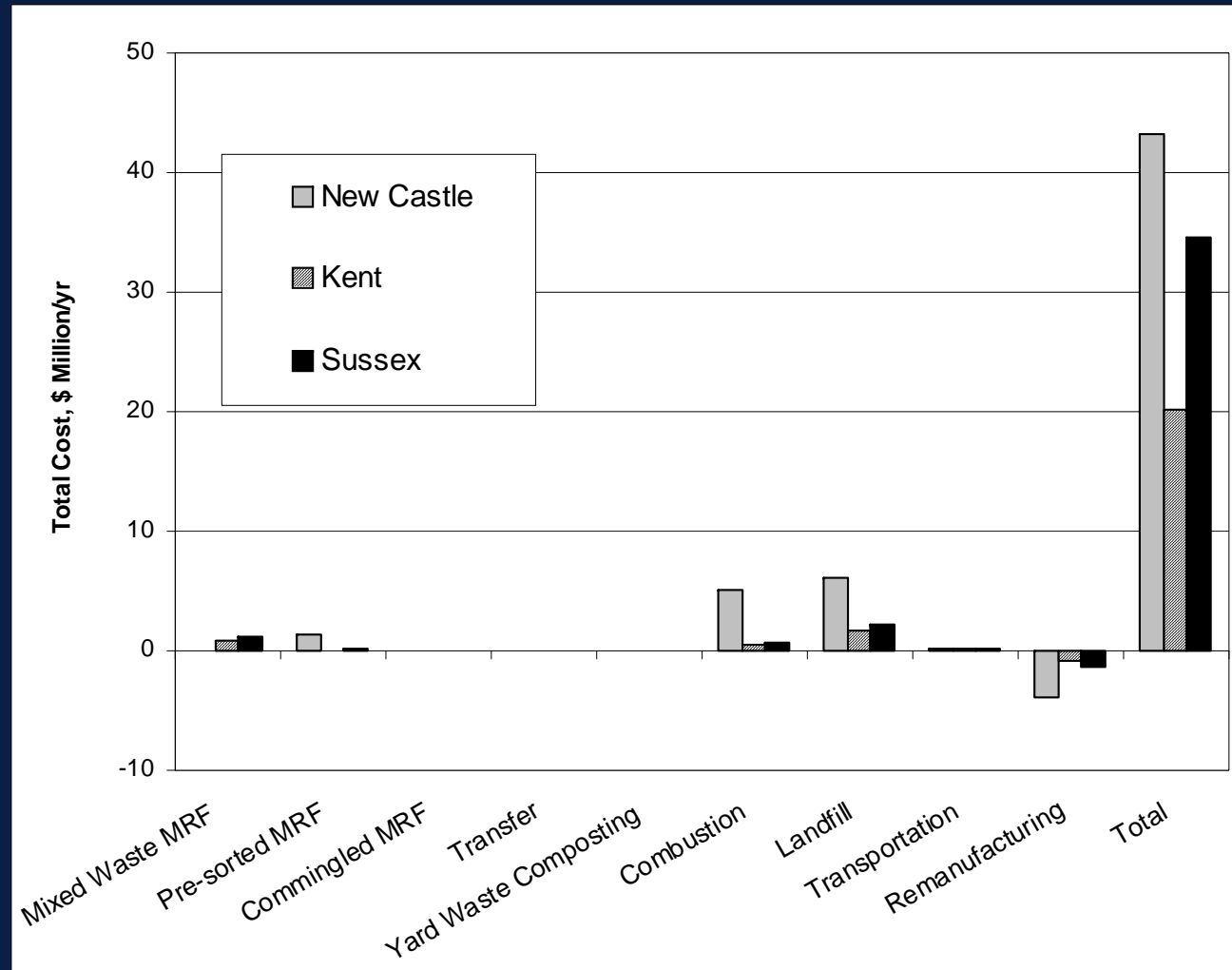
[curbside recycling + yard waste composting + combustion]



- The statewide optimum diversion strategy varies by county
- Between 50 and 70% diversion, all increases occur in New Castle County due to lower transport cost

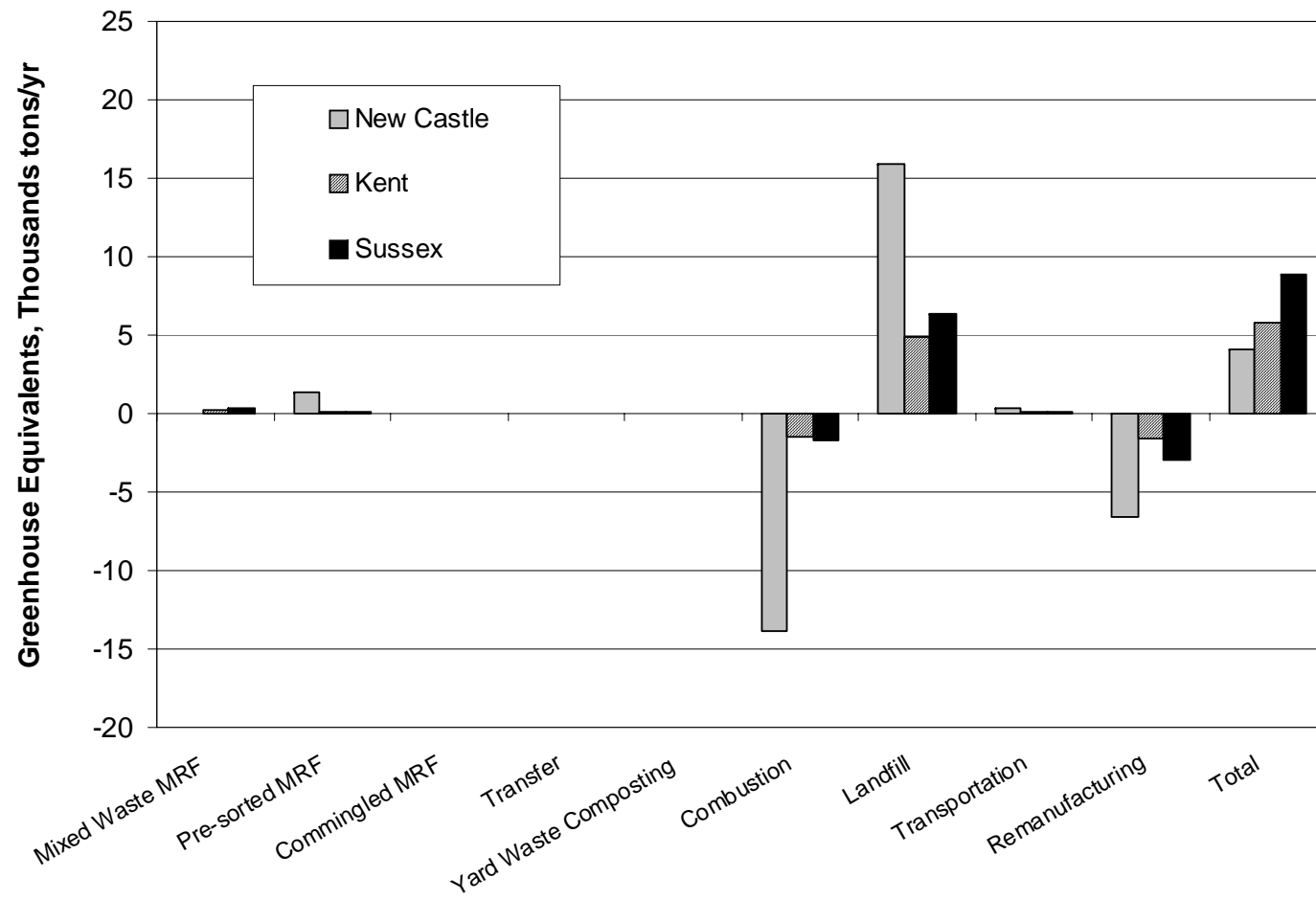
Cost Breakdown in Cost-effective 30% Statewide Diversion Strategy

[curbside recycling + yard waste composting + combustion]



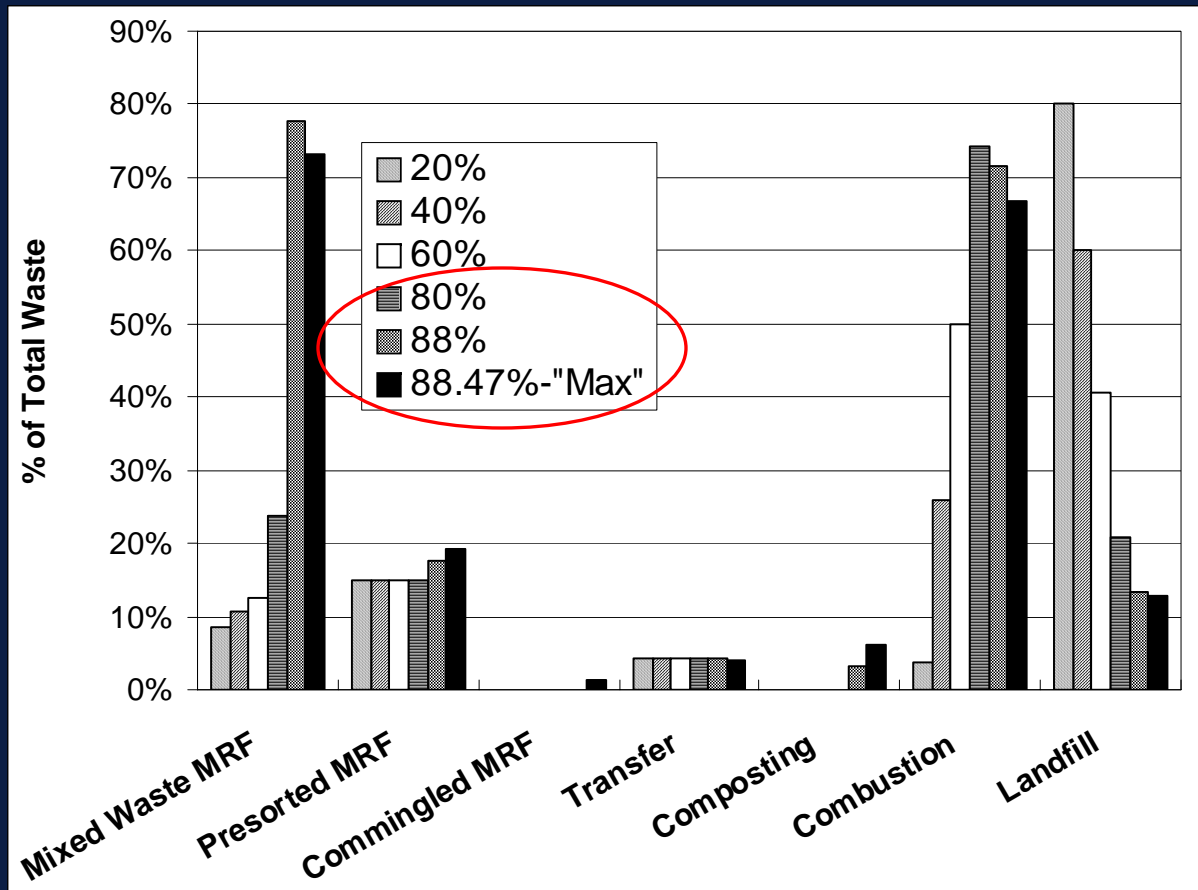
GHE Breakdown in Cost-effective 30% Statewide Diversion Strategy

[curbside recycling + yard waste composting + combustion]



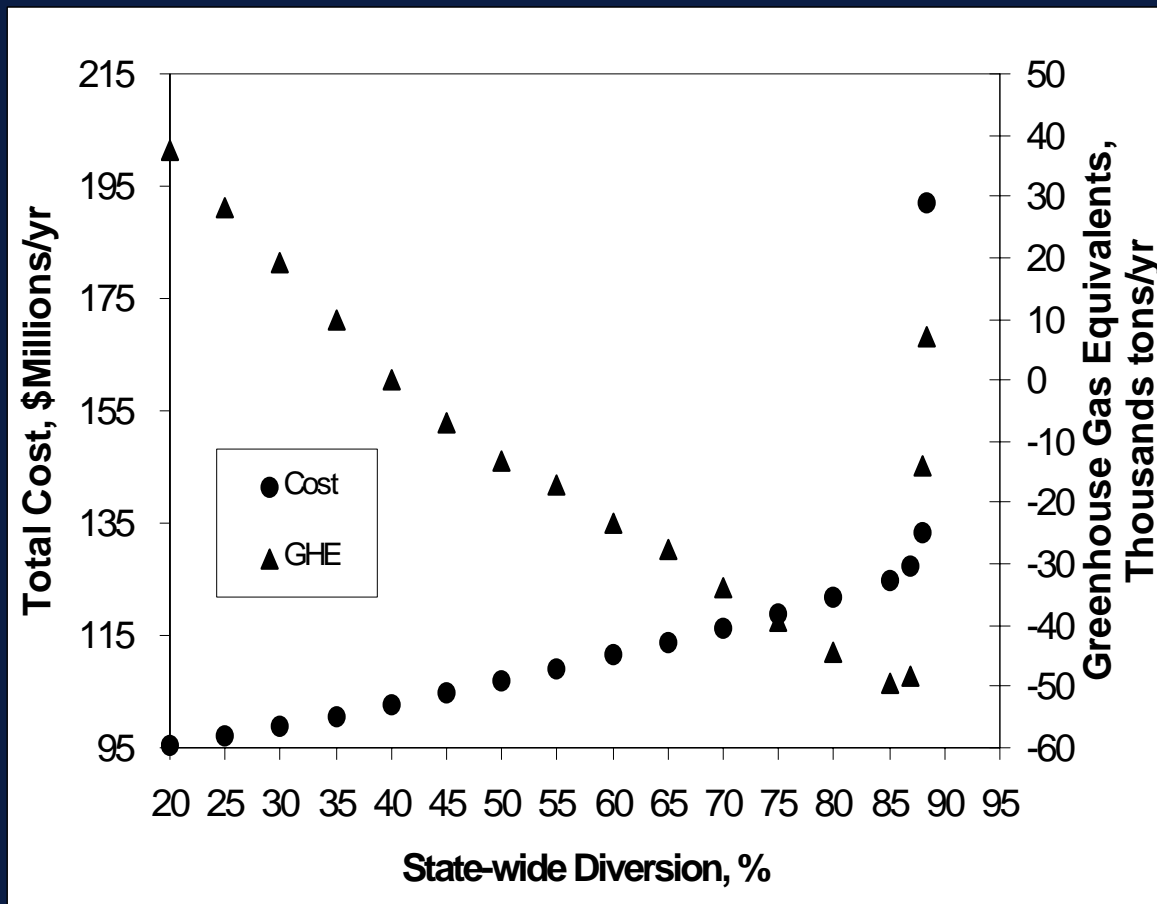
Variation of Waste Flows in Cost-effective 30% Statewide Diversion Strategy

[curbside recycling + yard waste composting + combustion]



- Composting and curbside recycling only utilized near maximum diversion when combustion is enabled

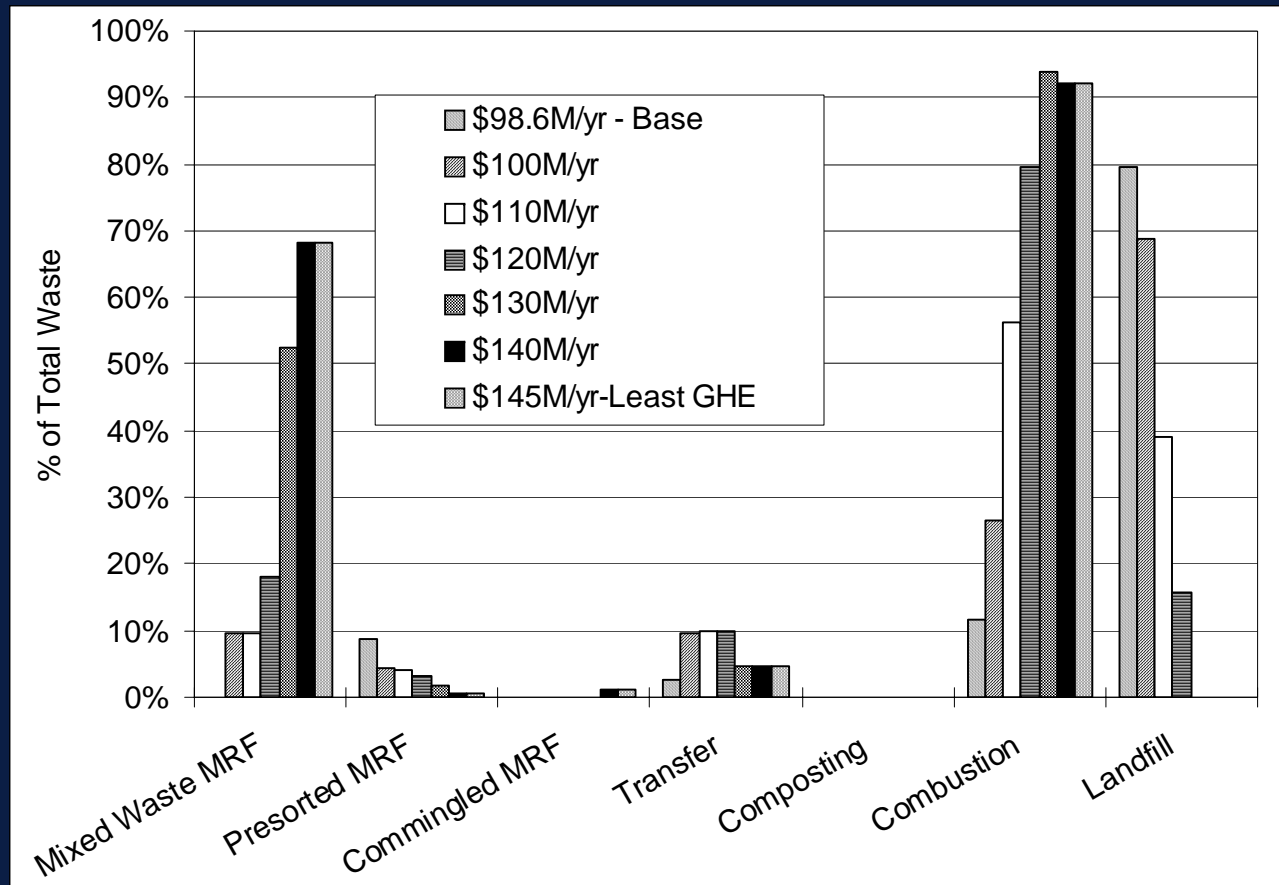
Variation of Cost & GHE with Diversion in Cost-effective 30% Statewide Diversion Strategy *[curbside recycling + yard waste composting + combustion]*



- GHE increases at the extreme due to implementation of composting and curbside recycling to meet diversion constraint

Waste Flows in **GHE-minimizing** Strategies

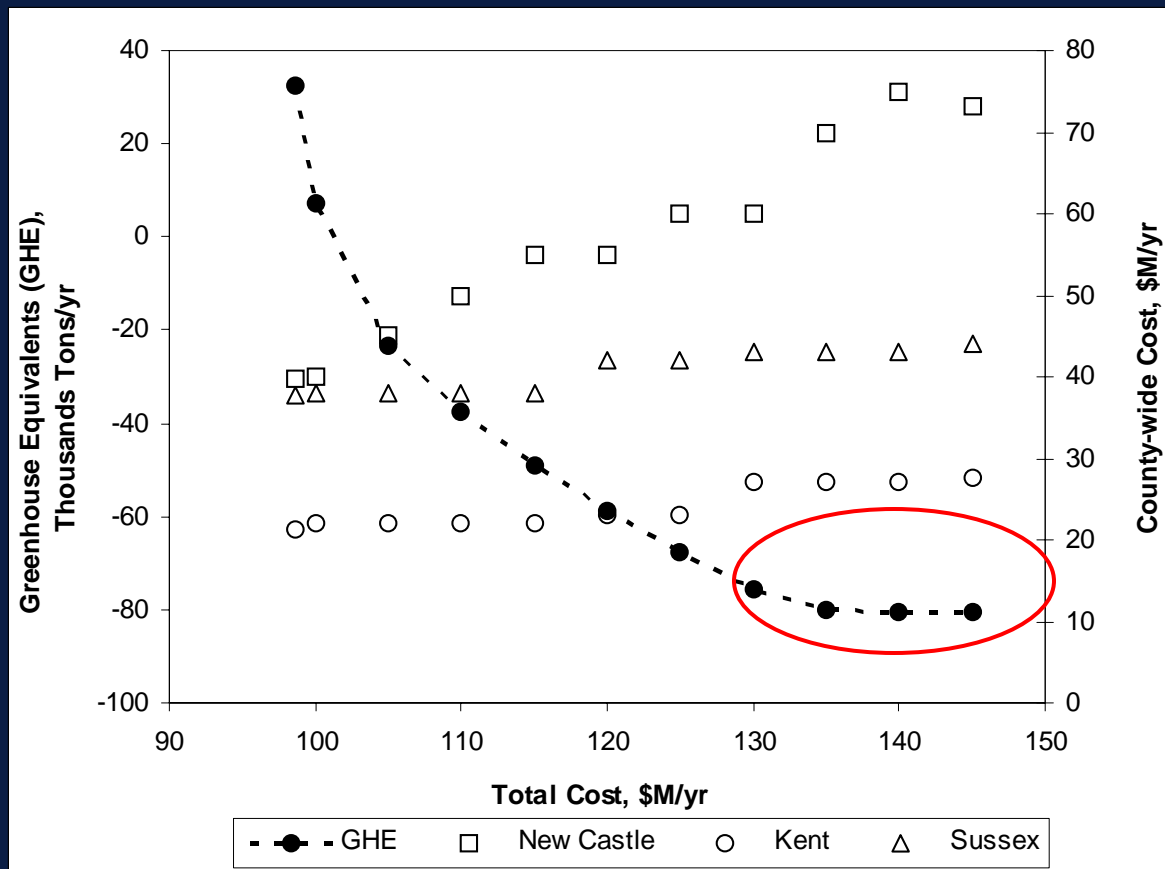
[curbside recycling + yard waste composting + combustion]



- Combustion increases as the cost constraint is relaxed
- Yard waste never utilized as no GHE offset
- Curbside collection only used near min-GHE scenario

Tradeoff Between GHE and Cost (using GHE-minimizing scenarios)

[curbside recycling + yard waste composting + combustion]




- Minimize GHE at increasing cost constraint
- No GHE benefit at increasing cost near minimum GHE

Observations from Statewide Analyses

- The optimal statewide strategy is a combination of three unique SWM alternatives that are county-specific
 - a uniform statewide strategy will be sub-optimal

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Generating Alternative SWM Strategies

- Optimal solution may not be appropriate
 - political feasibility
 - capital intensive
 - facility siting
 - ...
- Generate alternatives that maximize differences in unit operations & waste flow choices in SWM strategies

Generating Alternative Strategies

Cost-effective 30% statewide diversion strategy includes:

- cost-effective 35% diversion from New Castle

Cost: \$43.2 M/yr $\xrightarrow{\text{relax the cost}}$ \$48 M/yr

- cost-effective 20% diversion from Kent

Cost: \$20.2 M/yr $\xrightarrow{\text{relax the cost}}$ \$22.5 M/yr

- cost-effective 20% diversion from Sussex

Cost: \$34.6 M/yr $\xrightarrow{\text{relax the cost}}$ \$38.7 M/yr

Waste Flows for Alternative SWM Strategies to Achieve 30% Statewide Diversion

		Least-Cost	NC-Alt 1 + K-Alt 2 + S-LC	NC-Alt 2 + K-Alt 2 + S-Alt2
Mixed Waste Transfer	tons/yr	24394	19894	5330
Pre-Sorted Transfer	tons/yr	719	7185	5829
Mixed Waste MRF	tons/yr	73554	83665	124772
Presorted MRF	tons/yr	86696	32717	17290
Commingled MRF	tons/yr	0	7431	5745
Yard Waste Composting	tons/yr	0	13115	12496
Combustion	tons/yr	80564	118017	130325
Diversion	%	30	30	30

Three of 27 cases considered at each diversion level based on generation of 2 alternatives per county (3^3)

Cost & Emissions for Alternative SWM Strategies to Achieve 30% Statewide Diversion


		Least-Cost	NC-Alt 1 + K-Alt 2 + S-LC	NC-Alt 2 + K-Alt 2 + S-Alt2
Cost	\$/year	98,060,000	108,504,000	105,105,000
Energy	MBTU/year	-2,022,063	-1,894,368	-1,776,187
Total PM	lbs/yr	-1,013,081	-942,806	-736,587
NOx	lbs/yr	-560,727	-265,041	-222,019
SOx	lbs/yr	-2,584,434	-2,482,903	-2,372,025
CO	lbs/yr	418,973	1,077,938	1,522,636
CO ₂ -biomass	lbs/yr	585,195,295	650,697,534	654,434,958
CO ₂ -fossil	lbs/yr	-117,803,444	-186,878,075	-185,463,540
GHE	tons/yr	18,761	11,280	12,621
CH ₄	lbs/yr	12,161,215	12,838,604	13,239,244
Diversion	%	30	30	30

The alternatives perform differently with respect to cost and emissions

Observations from MGA Analysis

- The procedure illustrated here could be applied to scenarios for which further study is desired
 - Select alternatives with favorable traits

Where are we now?

- SWM-LCI Background
- Modeling Approach
- Data Collection
- County-specific SWM Strategies
 - Least-cost scenarios
 - Combinations of Curbside Recycling, Yard Waste Composting and Combustion
 - Consideration of Environmental Emissions
- Statewide SWM Strategies
- Alternative SWM Strategies
-  ▪ Uncertainty analysis

Consideration of Cost and Environmental Emissions Under Conditions of Uncertainty

- Objectives
 - Integrate uncertainty propagation procedures
 - Characterize and compare uncertainty in cost and LCI emissions estimates

Uncertain Parameters

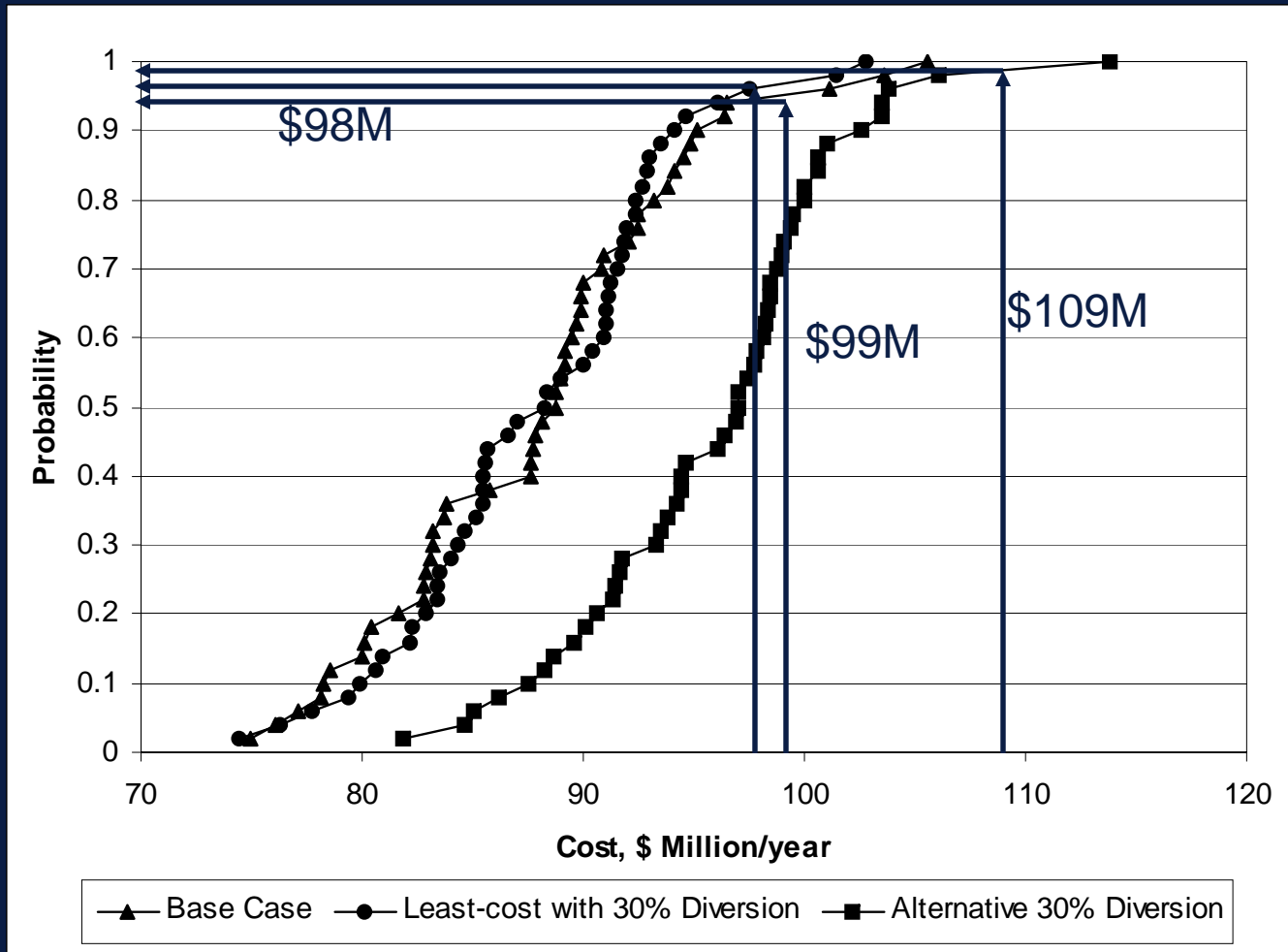
- Collection Process:
 - travel time between route and facility, number of houses per stop, loading time at one service stop, fuel usage rate
- Combustion Process
 - heat rate (kcal input/kWh)
- Material Recovery Facility
 - baler electricity usage rate
- Landfill Process
 - waste density, gas collection efficiency, decay rate, extent of methane oxidation
- Remanufacturing LCI Model
 - Emissions from raw and/or recycled material production such as ferrous, aluminum

Illustrative Results

- The procedure was applied to the cost-effective 30% statewide diversion case
- The least-cost and two alternatives were analyzed

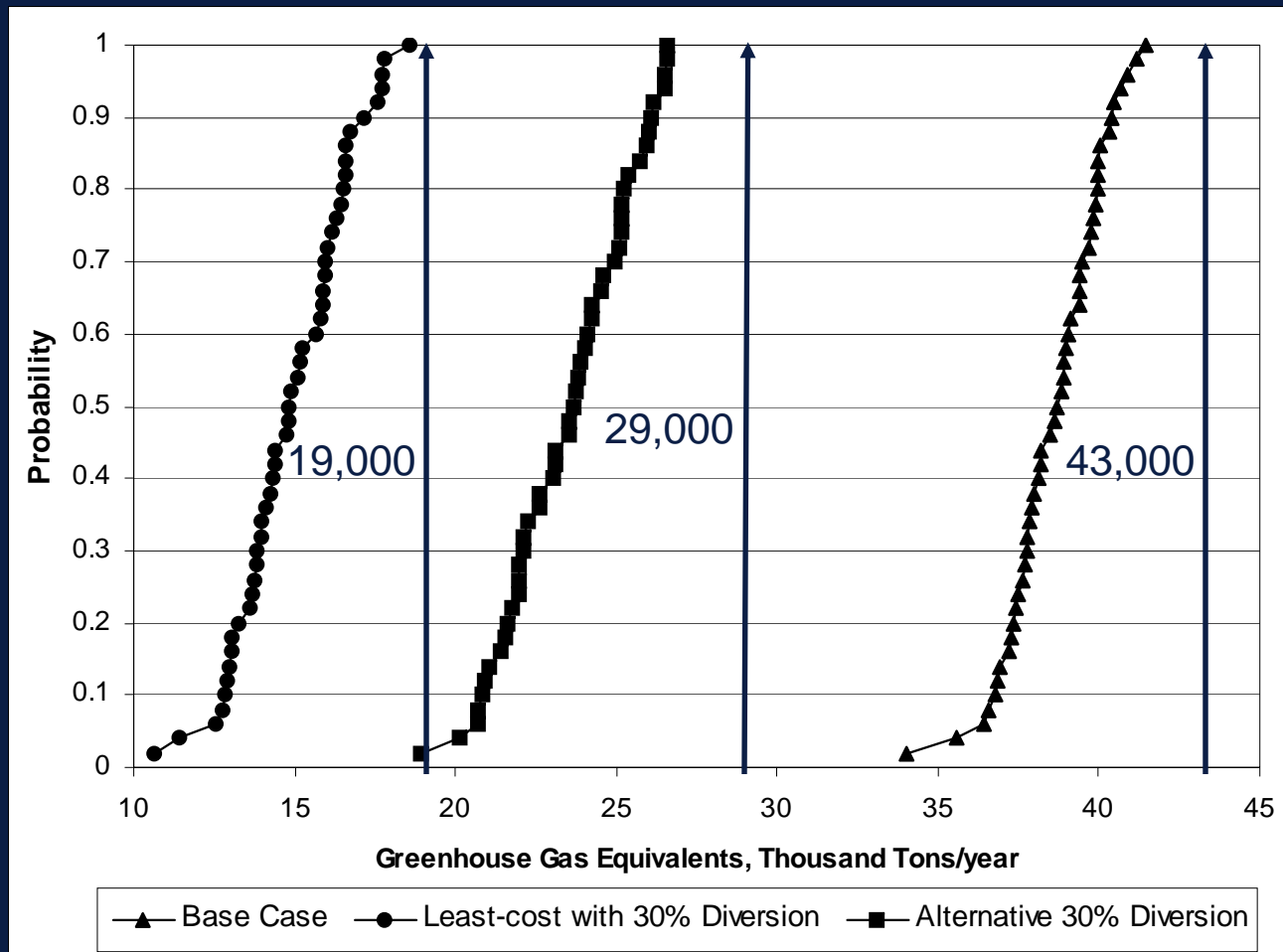
Uncertainty in Cost of Strategies for 30% Statewide Diversion

[curbside recycling + yard waste composting + combustion]



Uncertainty in GHE of Strategies for 30% Statewide Diversion

[curbside recycling + yard waste composting + combustion]



Summary

- Developed new procedures to use the model for a complex statewide analysis
- Demonstrated modeling to generate alternatives and uncertainty analysis
- Quantified tradeoffs among cost, diversion, emissions
- Provided counter-intuitive and creative results

The Answer Is

- Humans must still make decisions
 - Consider combustion, mixed waste MRF
 - Can we vary solid waste management by county, or even neighborhood?
 - Use model to document cost implications of this decision
 - What are the appropriate cost and emissions targets?

Going Forward

- Identify a narrow set of favorable alternatives for further exploration
 - Model could be constrained to utilize favorable traits of multiple alternatives
 - Consider locations of hypothetical new facilities
 - Detailed engineering analysis

Acknowledgements

- Delaware Solid Waste Authority